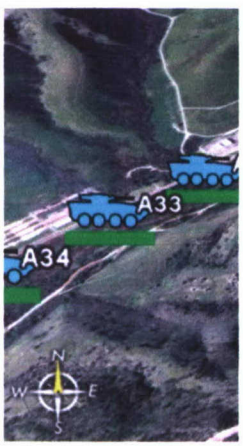
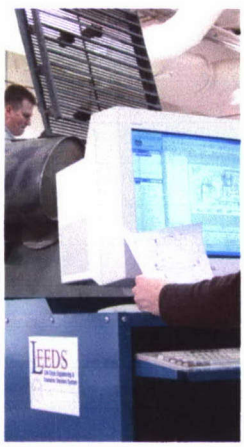
National Center for Remanufacturing and Resource Recovery (NC3R)

ROCHESTER INSTITUTE OF TECHNOLOGY

Office of Naval Research Grant N00014-03-1-0860

FINAL REPORT






R·I·T Defense Systems Modernization and Sustainment Initiative

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Table of Contents

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14. ABSTRACT

The National Center for Remanufacturing and Resource Recovery (NC3R) at RIT has successfully researched and demonstrated technologies that are able to enhance the performance of defense weapons and support systems, while managing total life-cycle costs. The program areas supported by this ONR grant were Asset Health Management, Life-cycle Engineering and Economic Decision Systems, Material Aging, and Modernization through Remanufacturing and Conversion. NC3R efforts included the development of remanufacturing processes for critical aircraft and ground vehicle components, reverse engineering and upgrade for obsolete fire control system components, development of military specification diagnostic and prognostic systems, design data and configuration management for Navy ships, and platform reliability availability and maintainability assessment.

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2. Executive Summary

The National Center for Remanufacturing and Resource Recovery (NC3R) at Rochester Institute of Technology was awarded the grant entitled Defense Systems Modernization and Sustainment Initiative (N00014-03-1-0860) from the Office of Naval Research (ONR) for the period May 1, 2003 to December 30 2005. The successful completion of the original award for $3,645,000 (May 1, 2003 to November 1, 2004) led to one modification of $1,826,950 in May 2004 extending the effort to December 30, 2005. This final report is provided in accordance with the grant requirements upon successful completion of the original grant including its extensions.

The National Center for Remanufacturing and Resource Recovery (NC3R) has successfully demonstrated technologies that are able to enhance the performance of defense weapons and support systems, while managing total life-cycle costs. For more than seven years, NC3R has collaborated with Department of Defense organizations, such as the Office of Naval Research, Naval Air Systems Command, Marine Corps Systems Command, Naval Air Depot – Jacksonville, Program Manager – Light Armored Vehicle, Marine Corps Combat Development Command, USMC Depot – Albany, GA, USMC Depot – Barstow, CA, and Navy Surface Warfare Laboratory – Carderock Division, in a wide variety of life-cycle engineering projects on several major weapons systems. For these organizations, NC3R has developed remanufacturing and conversion processes, programs to predict equipment health and failure, life-cycle technology insertion, rapid reverse-engineering processes, and material analysis technologies to predict service-life. For the grant specific projects completed, these efforts included the development of remanufacturing processes for critical aircraft and ground vehicle components, reverse engineering and upgrade for obsolete fire control system components, development of military specification diagnostic and prognostic systems, design data and configuration management for Navy ships, and platform reliability availability and maintainability assessment.

The efforts conducted by the National Center for Remanufacturing and Resource Recovery were separated into four programs areas, each with related projects. Asset Health Management, Life-cycle Engineering and Economic Decision Systems, Material Aging, and Modernization through Remanufacturing and Conversion were the major programs supported by this ONR grant. In 2004, the National Center for Advanced Technologies awarded its Defense Manufacturing Excellence Award to NC3R for its innovative contributions to the modernization of the nation's military systems. This recognition validates the relevance and importance of the four programs to DoD priorities.

Program areas are highlighted below.

1. Asset Health Management. Military operations require rapid and efficient response to changes in battlefield situations. This rapid response is made possible only by creating systems that provide total asset visibility and a common relevant operational picture that can effectively link warfighters and battlefield support agencies. Current and evolving information technology offers the potential for the sharing of real-time status between military units and their weapons systems. However, information access is not enough; commanders and logisticians also need decision support tools to aid them in analyzing and interpreting incoming data.

Asset Health Management (AHM) is defined as the complete set of processes that support the optimization of weapon system readiness and supportability. The ideal Asset Health Management system ties together technology enabled weapon systems and technology enabled maintainers, both with connectivity to critical support systems. In addition, the ideal Asset Health Management system also supports the information needs of battlefield commanders and logisticians.

There are a number of technology gaps and implementation issues that must be overcome before proactive health management can be achieved by the military. Table 1 below lists the functional capabilities required for AHM and the enabling technologies that were developed under this contract by NC3R to support them.

System Capability	Enabling Technology
On-board diagnostics and prognostics	- On-board data bus network and diagnostic computer - COTS sensors and components - Knowledge and model based systems for diagnostics - "Physics of failure," trend, and model based prognostics
Maintenance Aiding	- On-board diagnostics and prognostics - Knowledge based maintenance aiding system - Electronic portable (point-of-maintenance) aids
Remote monitoring (telematics)	- Data transmission and security mechanisms - Data analysis and visualization tools - Vehicle information interface description (for data transport)
Fleet trending and anticipatory maintenance	- Data collection mechanism (e.g. web-portal) - Data analysis tools (data mining, trending and prediction, etc...)

Table 2.1. Asset Health Management Enabling Technologies

AHM technology development efforts under this contract focused on technology that supports improved readiness and maintainability of current military platforms. Many current platforms are having their life cycle extended past the original design intent. This investment in AHM technology has greatly aided customers in achieving readiness goals while managing supportability costs. In addition, these technology investments have prepared current platforms to meet the evolving requirements for advanced decision support systems for battlefield Logistics and Command and Control (Autonomic Logistics). Specific accomplishments under this grant include the development of on-

board diagnostic systems for the U.S. Marine Corps Light Armored Vehicle (LAV) and High-Mobility Multipurpose Wheeled Vehicle (HMMWV) programs.

This grant also supported a new effort to begin the development of a Reliability Centered Maintenance Center of Excellence at NC3R. Reliability Centered Maintenance is a process for establishing an overall maintenance management plan for all types of equipment. In direct partnership with the Marine Corps, implementation focused on maintaining equipment function and utility as required by the equipment users in the specific operational context. This approach has already achieved, for the Light Armored Vehicle, improved performance, greater safety, fewer maintenance requirements, longer useful life, a quality database of information, and will ultimately reduce overall life-cycle costs. This Center will expand on reliability centered maintenance to include the continued development of technologies for condition based maintenance, sensing and fleet monitoring, and data analysis.

2. LEEDS® (Life-cycle Engineering and Economic Decision System) is a total system approach to optimizing life-cycle performance through planned modernization and step-by-step improvements in technological capabilities. LEEDS® was initially developed for the remanufacture of the SES-200. The same platform was recently reconfigured to demonstrate modern submerged hull technologies and is called the SEA FLYER. This ONR-owned vessel incorporates the LEEDS® data-system with a wireless portable laptop allowing greater mobile access to the system's store maintenance support and performance monitoring capabilities. This application has helped in the life-cycle maintenance of this and other vessels.

The development of LEEDS® during this period focused on improving the owner/operator's decisions relating to equipment life-cycle costs throughout system operating life, not only at end-of-life. LEEDS® serves as an efficient method for the identification, collection, and storage of pertinent system specifications from initial design and build activities. These specifications, in addition to the wealth of condition, performance and cost data that accumulates during a system's life cycles, has been warehoused in a centralized repository that allows LEEDS® to serve as an on-board maintenance support tool as well as a high-level performance monitor of key systems. Users now have the capability to assemble and manage enormous quantities of design, cost, condition, and performance data. Performance and cost alternatives now can be identified and updated easily by enabling users to frequently revisit maintenance, modernization, remanufacturing, operating costs and other variables throughout the life of a system.

As a result of this grant, RIT investigated and/or implemented the following key technologies for LEEDS®:

- Intelligent Maintenance Support (IMS)

- System Monitoring Portal into LEEDS®
- Platform Monitoring Role Up through LEEDS®
- Porting using multiple form factors (Hand held devices)

During the grant period direct support using LEEDS® was provided to the Program Manager's Office for the Light Armored Vehicle (PM-LAV), Naval Aviation EA-6B platform.

3. Material Aging is the change in the physical appearance, dimensions, or physical and mechanical properties of a component during its service life. These changes limit the useful life of the component and drive many of the critical decisions that face major systems program managers as they seek to extend the useful life of their platforms. Corrosion, stress fractures and weakening, and catastrophic material or structural failures are all serious problems that must be continuously addressed. During this contract period, material aging studies were performed on LAV and HMMWV components to characterize the material aging mechanics. This information was then used by Program Managers to improve the performance of these components and to develop the prognostics used in the asset health management program. The center also began structural and material analysis efforts on the EA-6B Prowler, managed by Naval Air Systems Command, Naval Aviation Depot, Jacksonville. Among the many projects that were worked on during this contract are the following:

- NC3R has performed material aging studies on the LAV planetary drive and EA-6B flaperon actuator to assess the root causes of failures that significantly impact equipment availability.
- The LAV planetary drive material aging analysis resulted in the development of prognostic approaches that were implemented as part of the on-board monitoring system.
- The EA-6B actuator study resulted in a design change that improved the reliability of the actuator. This proposal will support the physics of failure evaluation of hydraulic line failures on the EA-6B using the A-6 aircraft located at RIT.

In addition, this effort supported the technology development for nondestructive evaluation techniques to identify, classify, and monitor fatigue and corrosion.

4. Modernization through Remanufacturing and Conversion (MTRAC). The Department of Defense needs the latest technologies and capabilities to respond to ever-evolving defense challenges but must also balance the factors of technology obsolescence, need for improved product performance, life-cycle costs and time constraints. Once investments in systems have been made, other decisions come up

throughout that product's life such as when to upgrade, convert, repair, replace or remanufacture to protect the investment and keep equipment operating better and longer.

Keeping equipment systems up-to-date throughout their life is one way to preserve investments. Also, the ability to test new technologies before new investments are made could validate future expenditures and help make long-term readiness decisions. Modernizing systems by applying remanufacturing principles is the key to fielding new technologies at low cost, low risk, and with improved performance in a shorter lead-time. Operating costs and environmental costs can be kept low by modernizing legacy systems instead of purchasing new systems outright. This cost-effective way of producing new military platforms can minimize the costs of modernization and upgrades. It satisfies technology needs at critical moments while reducing lead times for procuring new systems.

NC3R under this contract developed technologies to modernize equipment through remanufacture and conversion. MTRAC is an organized approach for integrating remanufacturing into the full life cycle of a product or system. The MTRAC program has developed tools and process to aid in design for remanufacturing, remanufacturability assessments, cost estimations for upgrades, and advanced technology insertions. NC3R uses a unique combination of several expertise areas—analysis of material failures, analysis of structural integrity and performance, analyses that can diagnose a product's health and predict its remaining life, and experience in how to recover systems at the end of their lives—to help the Department of Defense manage their deployed asset investments.

MTRAC techniques have been implemented with the Office of Naval Research and direct service programs with spectacular results. A remanufacturing process was developed for LAV drive shafts. This process could save the depots millions of dollars per year at current production runs. Other supported programs included remanufacturing development for the LAV, EA-6B, and FA-18. Additionally, through this program NC3R developed a rapid reverse engineering process that was used to develop a technical data package and prototypes of critical communication board components for the Light Armored Vehicle C2 variant. This allowed for the life extension of the communication system through the next intended revision and could save as much as $3.3 million for the planned production run of 100 boards.

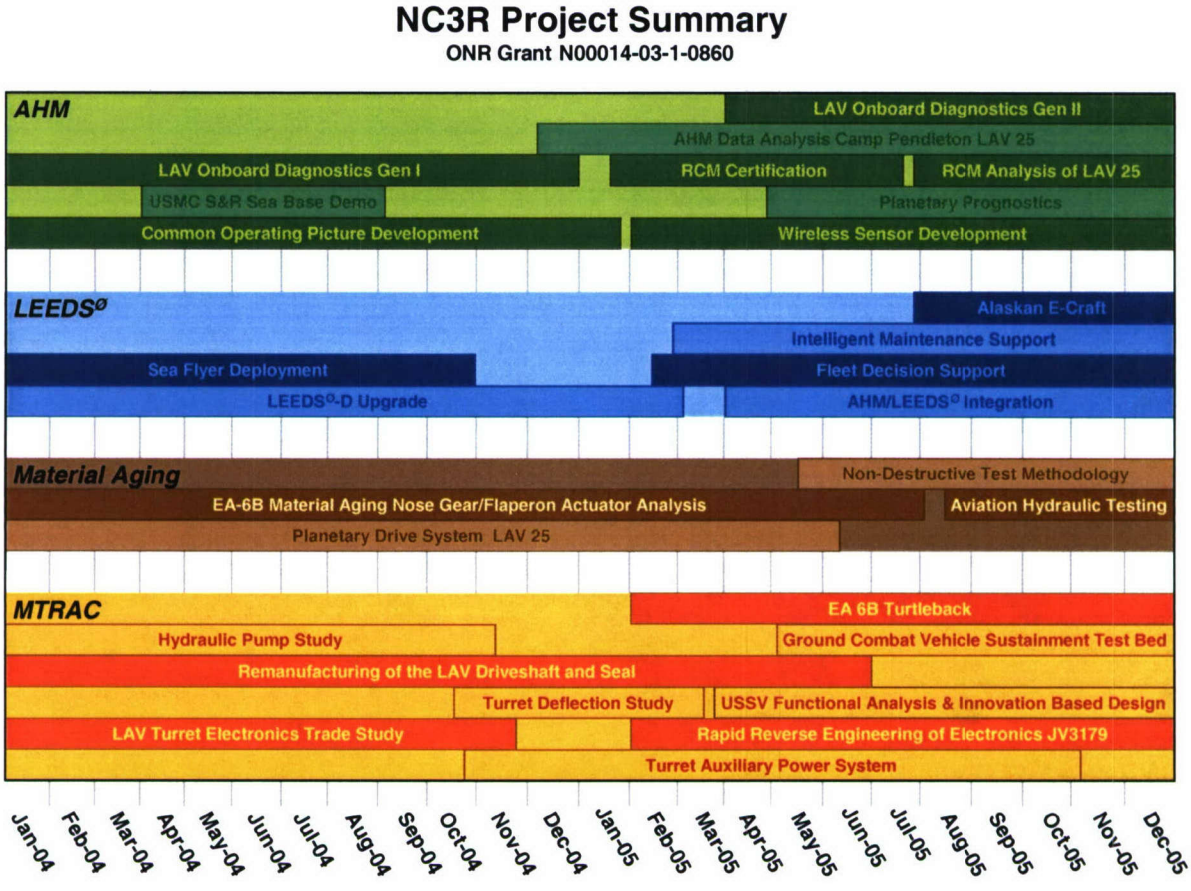


Figure 2.1. Project Summary by Program Area

Within the four major programs shown above, a total of 28 projects were completed and another 15 projects are ongoing. These projects in some cases were conducted to directly support the Office of Naval Research and in other situations, projects directly supported a particular warfare specialty office (USMC – Program Manager for Light Armored Vehicle for example). Each project was undertaken with a clear understanding of the problem and applied technologies were successfully developed at NC3R to solve the issues. Through applying new technologies, NC3R enabled significant technology advancement for legacy platforms and improvement of their operational readiness and availability. In addition, tremendous cost savings were realized through these efforts.

The National Center for Remanufacturing and Resource Recovery has proven to be a preeminent leader in the field of remanufacturing and system upgrades. The Center's continued achievements with industrial customers provide a unique perspective into commercial total life-cycle issues that are easily translated into proven successful solutions for the Department of Defense.

3. Introduction to the National Center for Remanufacturing and Resource Recovery at Rochester Institute of Technology

Founded in 1997, The National Center for Remanufacturing and Resource Recovery (NC3R) at Rochester Institute of Technology was the nation's first research facility devoted to the study of remanufacturuing.

CIMS building on the RIT campus

Today, NC3R is an international leader in remanufacturing and industrial reuse, sustainable design and pollution prevention. NC3R is a dynamic collaboration of over 40 dedicated engineers and technicians supported by RIT faculty and students. The center is currently housed in the Center for Integrated Manufacturing Studies (CIMS) on the RIT campus and takes advantage of the facility's 170,000 square feet of laboratory and office space, six research bays and 10 room, 400 seat conference and training center, equipped with smart capabilities.

Through its partnership with industry, the center has assisted numerous manufacturers in improving efficiency and enhancing environmental quality. Since 1998, NC3R has completed 640 technical assistance projects helping to create 683 new jobs, retain 795 more, reduce expenses by $8 million, and increase sales by $96 million.

In addition, NC3R has developed a unique partnership with the United States Military to enhance remanufacturing and reuse, reduce costs and ensure the safety of our troops in the field. For example, research conducted on the US Marine Corps' Light Armored Vehicle has extended the life of the existing fleet by 20 to 25 years, saving the military approximately $42 million.

The center was founded and continues to be led by Dr. Nabil Nasr, an international expert in sustainable design and environemntally consciuos manufacturing who has spent over two decades assisting companies and government agencies in enhancing profitability while also reducing environmental impact. Dr. Nasr currently serves on the National Research Council's Board on Manufacturing and Engineering Design and the National Science Foundation's Environmentally Benign Manufacturing Team. He is also chair of the Remanufacturing Industries Council.

One of several research bays

In response to the signicant impact the center's research has achieved, Dr. Nasr and NC3R has received several national honors, including the National Center for Advanced

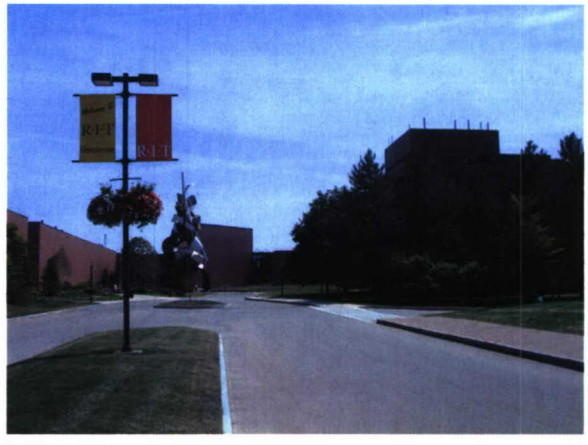
Technologies' 2004 Defense Manufacturing Excellence Award and the National Pollution Prevention Roundtable's 2006 MVP^2 award.

Rochester Institute of Technology (RIT)

Founded in 1829, RIT is an internationally recognized leader in professional and career-oriented education enrolling more than 15,200 students. RIT has one of the oldest and largest co-op programs in the world. RIT is coeducational, and the 11th largest privately held university in the nation.

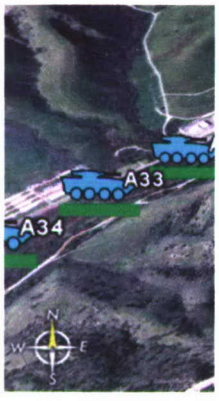
RIT offers 350 programs of study in eight colleges including the Kate Gleason College of Engineering, the E. Philip Saunders College of Business, and the B. Thomas Golisano College of Computing and Information Sciences. The university is internationally respected for its research and educational programs in imaging and color science, photography and remanufacturing as well as its work in experiential learning and cooperative education.

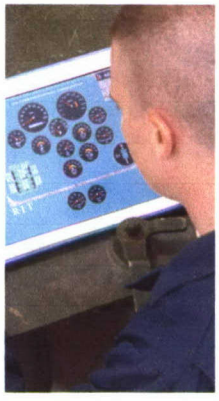
RIT's modern 1,300-acre campus is located in Rochester, the third largest city in NewYork State.



RIT campus

Asset Health Management



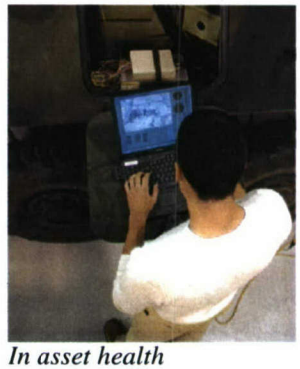


4. Asset Health Management

4.1. Description of Asset Health Management

Asset Health Management (AHM) is a process for optimizing the use of equipment by balancing operational requirements against maintenance and logistics capabilities.

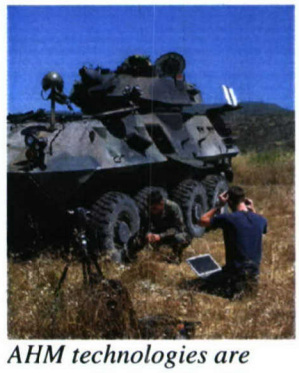
AHM systems consist of hardware and software components which monitor equipment usage and health, maintains equipment life-cycle histories, and reports their status on a reoccurring basis to improve the awareness by logistics and command and control groups.



In asset health management, embedded systems monitor equipment health

Asset Health Management – is the development of technology which is critically necessary to realizing Autonomic Logistics and achieving Department of Defense readiness goals. Asset Health Management will result in improved operational and maintenance efficiency for current and future military systems.

The Department of Defense (DoD) has accelerated its transformation to better meet the challenges of the 21st century through its Network Centric Warfare (NCW) Initiative. The Department of Navy (DoN) is supporting this transformation by delivering new military capabilities and dramatically enhancing current capabilities that ensure access and power projection from the sea. New strategies for military operations (such as Seabasing) that require DoN to project, protect and sustain their naval forces from the maritime domain are driving the need for more mobile force structures, new logistical support concepts (sense and respond, and autonomic logistics), and more sustainable weapons platforms. Furthermore, all the military services across the DoD are directing greater levels of readiness from new and existing weapons platforms along with support systems that provide a "shared awareness" that is characterized by improved battlefield information access with more robust communication channels and better logistical/asset health visibility for all levels of command. NC3R's research has focused on those technologies that will help the military services comply with the NCW initiative as directed by the DoD's Office of Transformation.



AHM technologies are repeatedly tested at Camp Pendleton

Asset Health Management (AHM) is a process for optimizing equipment readiness; balancing operational requirements against maintenance and logistics capabilities, and managing the cost of operations and support. Figure 1 illustrates the application of AHM

technologies, in a shared awareness NCW environment, from the warfighter and platform through the echelons of command and maintenance to the enterprise level. Figure 4.1 also illustrates where the AHM technologies that have been developed by NC3R during this contract period apply within the entire military enterprise.

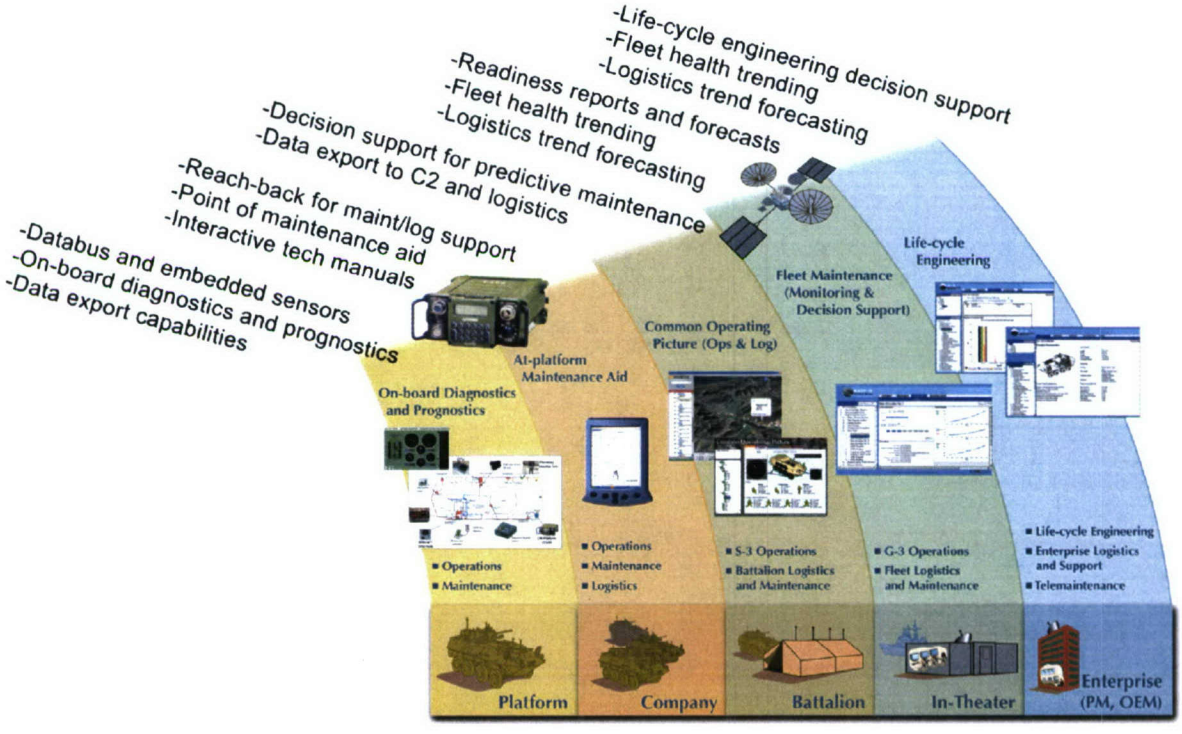


Figure 4.1. AHM Technologies and Applications

Smart sensors and on-board monitoring systems allow the health, location, and supply status of military platforms to be determined and analyzed. This information can be considered in the context of the operational requirements that are necessary to determine the optimal strategy for logistics support and equipment maintenance. Decision support systems enable these decisions to be made effectively at various levels (unit, company, and battalion) considering increasing numbers of platforms. Ultimately, this information can be aggregated across an entire fleet of like platforms to make enterprise level logistics and engineering decisions that take into account life-cycle cost and readiness implications. AHM, when fully realized, will support the joint transformation goals of networked awareness and distributed sensors and will give warfighters a tremendous advantage in operational/logistical tempo.

The full benefits of an Asset Health Management system are realized when all of the key elements are implemented in a seamless system-to-systems approach. Table 4.1 illustrates some of the key AHM system capabilities and associated enabling technologies that NC3R has worked on during this contract period.

System Capability	Enabling Technology
On-board diagnostics and prognostics	- Platform sensors, on-board databus network, and diagnostic computer - Knowledge and model based systems for diagnostics - "Physics of Failure," usage, and condition-based prognostics
Maintenance aiding	- On-board diagnostics and prognostics - Knowledge-based maintenance aiding system - Electronic portable (point of maintenance) aids
Remote monitoring (telematics)	- Data transmission and security mechanisms - Data analysis and visualization tools - Standardized interfaces for data transmission
Predictive maintenance	- Reliability Centered Maintenance (RCM) Analysis - Prognostic algorithms (time, usage, condition, and physics of failure based)
Fleet analysis and trending	- Fleet data collection and aggregation mechanisms - Data analysis tools (data mining, trending and prediction, anomaly detection, etc.)

Table 4.1. Asset Health Management Enabling Technologies

Technology Gaps and Research Objectives

There are still technology gaps that must be closed in order to achieve the full functionality represented by the system capabilities shown in Table 4.1. The research goals during this contract period of the Asset Health Management program are closely aligned with the Materials Aging and LEEDS® (Life-cycle Engineering and Economic Decision System) programs at NC3R to assist in closing these gaps.

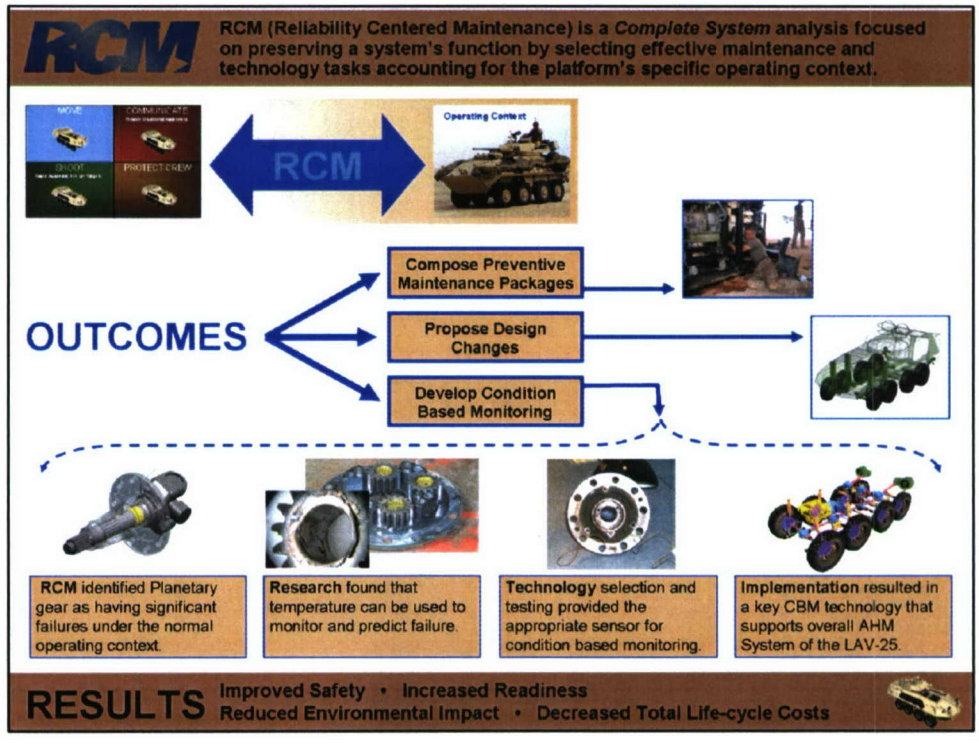
Figure 4.2 (at the end of this section) illustrates how the technology being developed by the Asset Health Management program during this contract period is filling the technology gaps while producing useful applied solutions for a variety of DoD programs. A driving principle behind our research program is to field validate our technology and work with our DoD partners toward successful transition.

Collaborative research between NC3R and DoD partners

In research to date, the Asset Health Management program has focused on developing and demonstrating technology for on-board diagnostics and prognostics for legacy military ground vehicles. The NC3R monitoring system has been collecting data on an operational LAV at Camp Pendleton, CA for the last year. This field testing has documented

the military value of on-board monitoring, and has also identified opportunities for system capability expansion. Also in the last year, we have begun to develop technologies for off-platform data analysis. These technologies are being applied at the platform level, and are also being extended to the prognostics for mechanical systems. In addition, methodologies for accelerated testing of electronics failure and reliability are being developed as a precursor to true prognostics on electronics components. An additional capability that has been developed over the past year is the use of Reliability Centered Maintenance (RCM). Reliability Centered Maintenance is the basis of the development of predictive (anticipatory) maintenance. We have begun the application of RCM to the USMC Light Armored Vehicle as a means of identifying opportunities for improvement of LAV readiness and operational safety. RCM also is being used to identify the areas of highest value for platform sensing and condition based maintenance.

The aim of our research during this contract period has been to advance the elements of the AHM system towards larger scale field-testing and validation in order to enable proactive health management of military equipment. The projects outlined in the following section illustrate how NC3R is working to successfully achieve these goals.



LAV RCM analysis

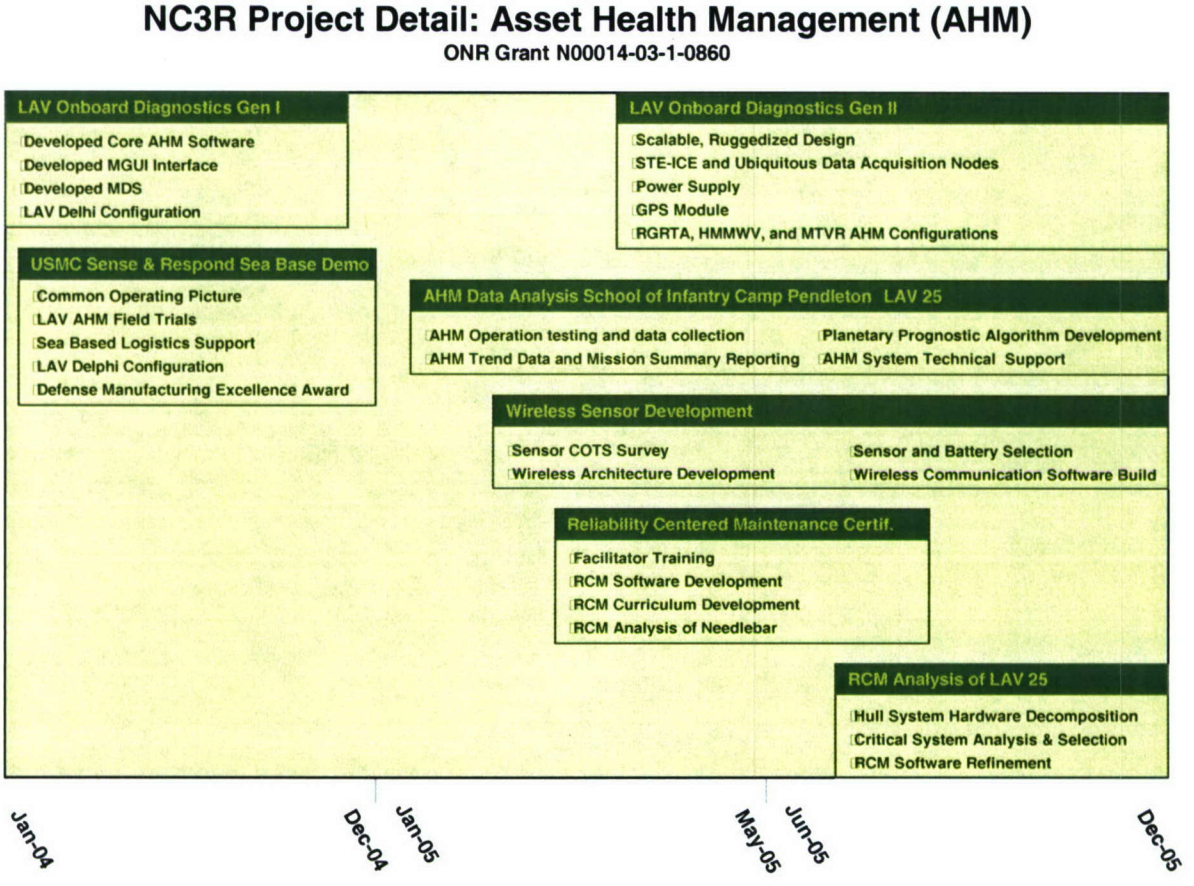


Figure 4.2. Primary AHM Projects

4.2. Asset Health Management Projects

As shown in Figure 4.2, the primary projects that were conducted under the Asset Health Management program include:

Ongoing Projects

- Asset Health Management Hardware
  - STE-ICE
  - Data Acquisition Node
  - UPS
  - Power Supply
  - GPS Module
- Asset Health Management System Development and Deployment
  - AHM Deployment/Validation: Rochester Genesee Regional Transportation Authority (RGRTA)
  - Hardware and software upgrades and deployment: USMC LAV Gen II
  - Demonstration Systems:
    - USMC Medium Tactical Vehicle Replacement (MTVR)
    - HMMWV

- Wireless Planetary and Differential Sensors
- National Center for Manufacturing Sciences (NCMS II): LAV Life Cycle Monitoring Support
    - Common Operating Picture
    - Data Analysis Support
- RCM Analysis of Light Armored Vehicle
    - RCM Analysis Software Tool
    - Platform Level LAV-25 Analysis, Completed Sept 2005
    - RCM Analysis of the Pneumatic System
- Fleet Data Visualization and Decision Support
    - AHM/LEEDS Integration
- Electronic Reliability and Electronics Prognostics
    - HALT/HASS Reliability Laboratory Development
- AHM Data Analysis Methodologies

Completed Projects

- USMC Sense and Respond and Seabasing Demonstration (November 2004)
- Light Armored Vehicle: On-Board Diagnostics Development (December 2004)
- Asset Health Management Software (December 2004)
    - Core AHM
    - MGUI – Graphical User Interface for AHM data
    - MDS – AHM Data Synchronizer
    - Gen I LAV Application
- Hull turret optical bridge link analysis for the Light Armored Vehicle (July 2005)
- Common Operational Picture (COP) (October 2005)
- RCM Certification of Facilitators (November 2005)
    - Needle Bar

The projects are fully described in the next section.

Asset Health Management

PROJECTS

Asset Health Management

Ongoing Projects

1. Asset Health Management Hardware

Project Goal

Develop hardware for a second generation Asset Health Management (AHM) system. Evaluate the field performance of first generation (AHM) hardware based on the feedback from the LAV fielding at Camp Pendleton, California. Design and build 2nd generation hardware components that facilitate a scalable and manufacturable system for application to a larger number of military vehicles.

NC3R deployed its AHM Gen I system and software on an LAV 25 at Camp Pendleton, California in December of 2004. This has allowed the center to field test its hardware for an extended period of time under varying loads and conditions. Feedback from the Marine Corps during this period has been very favorable and has generated the need for a follow-on system that can be manufactured and built for a larger number and differing types of vehicles. Hardware is being designed and built that will not only extend the capability of the AHM system but is modular in nature so that a system can be readily tailored both in collection complexity and cost. Hardware decisions are also being made considering the ease of manufacturing, ability to meet military standards, and robustness of the system.

Project Results to date

- NC3R has designed a data acquisition component that can directly read the collected signals from the Standard Test Equipment for Internal Combustion Engine (STE-ICE) and transmit the data over a J1939 databus. This will allow the AHM system to be quickly applied to a number of legacy platforms equipped with STE-ICE capability.
- NC3R has designed a generic Data Acquisition (DAQ) Node that is capable of interfacing to a wide range of sensors and transmitting the data over a J1939 databus. The component is designed to be low cost so that it provides the flexibility for a scalable AHM system design – tailored to the needs and budget for a particular platform.
- NC3R did an extensive survey and benchmarking of Uninterruptible Power Supply technology for possible application to an AHM system. The first design concept has been completed for a UPS board to support the next generation AHM system for the LAV.
- NC3R completed the first design concept and preliminary drawings for a power supply to provide clean power and protect the AHM system from various electrical system anomalies in accordance with applicable military specifications.
- NC3R a first prototype of a low cost Global Positioning System (GPS) node that can provide location data over a J1939 databus.

2. Asset Health Management System

Project Goal

Develop and deploy a second generation LAV AHM system based on the feedback from the deployment of the first generation system at Camp Pendleton. Verify the functional capability, versatility, and scalability of the system through the application of the program to a number of other platforms.

NC3R deployed its AHM system to an LAV 25 at Camp Pendleton, California in December of 2004. This has allowed NC3R to field test the integrated system for an extended period of time under varying loads and conditions. The feedback on functionality from the deployment of the first generation system, and attention to fieldability and cost issues (for the LAV as well as other ground vehicle platforms) have been the focus of the second generation system development. The current plan calls for deployment of the generation II software and hardware in 2006. Additionally, NC3R is working with the Office of Naval Research and Rochester Genesee Regional Transportation Authority (RGRTA) to develop a local (Rochester area) test platform to aid in verifying the system components on a high usage application. This effort will also serve as a test bed for the development of fleet monitoring technologies. Two other platforms are being used to evaluate the flexibility of the system architecture – the AHM system is being applied to a second legacy vehicle (High Mobility Multi-purpose Wheeled Vehicle - HMMWV) and will be applied to a new platform which comes equipped with an OEM databus (Medium Tactical Vehicle Replacement - MTVR).

Project Results to date

- NC3R has deployed and supported the first generation system for 12 months of field collection data at Camp Pendleton, California – no hardware or software failures were experienced during vehicle operation. Feedback from system functionality was used to direct development of 2nd Generation RIT system and also the PM-LAV directed NCMS phase II effort.
- Various LAV health and operational (operating procedures) anomalies were detected during the field test. Vehicle usage and anomaly reports were provided to PM-LAV and to the USMC unit maintenance and operations officers.

3. Wireless Planetary and Differential Sensors

Project Goal

Design a small wireless device that is modular in design with a "plug in" sensor that can support the most common remote sensor requirements for condition based monitoring of military platforms.

Wireless planetary sensor

NC3R's experience in applying AHM to different military ground vehicles has generated a need for data that can only be acquired by sensing the state of various parts, lubricants, and sub-systems that are

difficult or impossible to sense with wired components. In particular, the LAV has critical drive train components that cannot be monitored with wired sensors. The requirement for a versatile wireless monitoring device that can interface to a vehicle databus and also meet the environmental requirements of a military is not being currently met by the commercial marketplace. In order to provide accessibility to critical signals that are needed to develop health assessment methodologies, NC3R is developing a prototype wireless sensing system that will interface with a J1939 databus. This system should be ready for the Gen II system deployment in the fall of 2006.

Project Results to date

- NC3R conducted a market survey and benchmarked the following technologies:
  - Battery, one-time use, rechargeable, packaging
  - Power scavenging techniques
  - Wireless Schema, networks, and associated hardware
  - Low power, profile antenna
  - Low power sensor devices
- Developed a Statement of Requirements and Project Plan for the development of a wireless temperature sensor.
- Began bench testing first prototypes of wireless sensor system that interfaces to the J1939 databus.
- Began initial battery testing for down-selection.

4. National Center for Manufacturing Sciences (NCMS) Common Operating Picture (COP) and Data Analysis Support

Project Goal

Provide a COP for use by the Marine Corps School of Infantry and analyze the Asset Health Monitoring data collected from the fleet of ten (10) vehicles that was installed by a NCMS collaboration of industrial and military partners.

NC3R teamed with the National Center for Manufacturing Sciences (NCMS), the Program Management Office for the Light Armored Vehicle (PMLAV), the Naval Weapons Station Crane Joint Distant Support and Response (JDSR) team, and a number of industrial partners in an effort to install an AHM monitoring system on a fleet of vehicles at the School of Infantry at Camp Pendleton, California. As part of the effort, NC3R was asked to provide a COP to visually demonstrate the capability provided by a fleet of vehicles that had an onboard AHM system to all the stakeholders. The newer version of the COP was demonstrated at the 2005 Defense Maintenance Symposium. Finally, as the data is amassed by the onboard systems, NC3R will analyze the information to look for ways that it can be exploited by PM-LAV in the areas of autonomic logistics, condition based maintenance, material aging, diagnostics, and prognostics. This data analysis effort is scheduled to begin in October of 2006.

Project Results to date

- RIT has developed a database transformer that can:
  - Quickly extract the information necessary to run the COP from the overall sensor database.
  - Run as a periodic service that can recognize when a vehicle has been updated and begin the extraction.
- Extended the capability of the COP to allow for:
  - Playback of pre-recorded mission data directly from the database.
  - Improved and simplified user interface that allows for tabbed sections for operations, maintenance and logistics, better graphics, and more intuitive information retrieval.
- Began the development of a software algorithm to do anomaly detection, trending, and future state prediction for the LAV planetaries.
- Coordinated with JDSR to develop the procedures, including the required security measures, for transferring the data rapidly back from the vehicles in California to NC3R.

The COP analyzes the Asset Health Monitoring data collected from a fleet of vehicles.

5. Reliability Centered Maintenance (RCM) of LAV 25

Project Goal

Conduct an RCM analysis of the LAV 25 in order to develop a maintenance program, reduce operating costs, look for CBM technology opportunities, and make recommendations for the next generation vehicle design modifications.

NC3R teamed with PMLAV and active duty United States Marines from 2nd LAR Battalion and the Marine Detachment from Aberdeen Proving Grounds to conduct a detailed RCM analysis of the LAV. NC3R began by assisting PMLAV in setting up an RCM program and schedule for implementation of the analysis. A team of engineers from NC3R then conducted an overall investigation of the hull systems of the LAV to include a functional breakdown, hardware partitions, FMEA. Upon completion, NC3R analyzed the results, rank-ordered

subsystem criticality, and presented the results to PMLAV. A detailed analysis of the first subsystem, Pneumatic, was to be completed in the spring of 2006.

Project Results to date

- Developed and delivered a customer specific RCM workbook and class for the training of ten students from PMLAV, Marine Corps Depot Albany, and NC3R engineers.
- Completed the overall analysis of the LAV 25, major subsystems of the hull.
- Down selected and presented the most critical subsystems to PMLAV for prioritization.

6. Fleet Data Visualization and Decision Support

Project Goal

Integrate the capabilities of the NC3R Asset Health Management (AHM) program and the Life-cycle Engineering & Economic Decision System (LEEDS®) in order to use the AHM generated historical data for making platform based assessments, a foundation for making overall fleet level management decisions.

NC3R's AHM program to date has focused on the monitoring of individual assets using data collected from a network of sensors that is then processed by a main system health node that interprets this information into a series of meaningful alerts and events. This data can be used to assess the overall health of the individual vehicle. LEEDS® software is a database and decision support system for long-term systems management of large, complex platforms, allowing for performance and cost alternatives to be clearly mapped when making life-cycle decisions about maintenance, remanufacturing, operating costs, and modernization efforts. During this contract period, NC3R began the effort to merge the capabilities of these two programs in order to take platform level maintenance histories, usage statistics, trend analysis, and system health captured by the AHM program and port to LEEDS® to make better informed decisions as part of a Total Systems Life Cycle Management (TLCSM) process.

Project Results to date

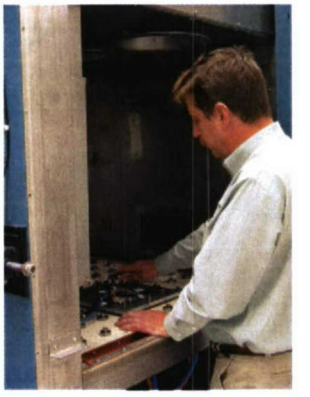
- Developed a technology survey and benchmarking of software to be used as an interface between AHM and LEEDS®.
- Developed the first set of algorithms for trending alerts and discriminating between system or signal causes.
- Developed a prototype portal within LEEDS® to display AHM data, with the ability to drill down into lower level alerts.

7. Electronic Reliability and Electronics Prognostics

Project Goal

Develop a Highly Accelerated Life Testing/Stress Screening (HALT/HASS) laboratory and methodologies for accelerated testing of electronics failure and reliability as a precursor to the development of prognostics for electronic components.

NC3R is in the process of developing the capability to do accelerated testing of electronic systems to identify and characterize design and manufacturing characteristics that affect reliability, durability and overall robustness. This capability will support future research in health monitoring technologies that predict impending failure and/or remaining life of electronic systems. A component of the LAV AHM system is being used as a test case for technology development. Reliability Centered Maintenance (RCM) analysis has been completed on this component with an eye toward identifying the critical functions and stressors that should be monitored.



HALT/HASS accelerated testing

Project Results to date

- NC3R has acquired and installed an Allegan OVS-3 Environmental Test Chamber for HALT/HASS testing.
- NC3R conducted an RCM analysis of an AHM power supply component in order to identify opportunities for condition monitoring.

8. LAV Data Analysis and Planetary Prognostic Algorithm Development

Project Goal

Collect data from an onboard Asset Health Monitoring System that is performing in an operational environment and use this information for prognostic algorithm development.

NC3R installed an Asset Health Monitoring system on board a Light Armored Vehicle at the School of Infantry in Camp Pendleton, California that was used for crewmen and leader training. The onboard system is currently collecting data during an assortment of missions including on-road, off-road, and swimming. NC3R was given unlimited access to the vehicle, data, and operators in order to gather information about the performance of the system, and based on this suggested changes that will be incorporated into the follow on system. Data collected was also used for the development of more robust planetary algorithms and trending/fleet monitoring efforts.

Project Results to date

- NC3R implemented the first fully operating LAV monitoring system, which been collected data up through the end of 2005.
- NC3R developed surveys and collected feedback from Marine Corps Commanders, Operators, and Maintainers to begin building the requirements and documents needed for the development of the next generation Asset Health Monitoring System.
- NC3R has used the collected data for trend analysis and begun development of planetary prognostics algorithms.

Field testing at Camp Pendleton

Completed Projects

1. USMC Sense and Respond and Seabasing Demonstration, Completed November 2004

USMC Sense and Respond and Seabasing Demonstration

Project Goal

Complete a live demonstration of the US Marine Corps' future logistics state.

NC3R was part of the team that demonstrated the end state of the Marine Corps logistics transformation process. The NC3R goal was to provide state of health and supply information from an LAV to an off-board command and control display, and also to implement connectivity to an off-shore sea-based support ship.

Project Results

- NC3R developed the on-board diagnostic system that provided information about the health and supply state of the LAV to a logistics support network.
- Captured live LAV data to be used for playback in a Sea-based logistics demonstration scenario. On playback, the raw data was passed through an operational AHM and data communications system.
- NC3R Linked an LAV maintainer in Houston to a live, sea-based support unit stationed on the ONR Sea Flyer off the coast of California.
- The project demonstrated the Marine Corps progress to date in Sense and Respond as well as the ultimate vision for USMC logistics.

2. Light Armored Vehicle: On-Board Diagnostics Development, Completed December 2004

Project Goal

Develop on-board diagnostic capability, provide interface for data extraction to off-board LAV web-portal and Smart Maintainer tool, and integrate automotive sensor technology into LAV databus.

NC3R worked with PM-LAV to develop, demonstrate, and field a base monitoring capability that was cost effective and supported future expansion options.

Project Results

- Databus data transport specifications and off-board data extraction specifications were developed
- Sensor technology was integrated into NC3R's on-board monitoring system for the LAV: engine oil quality monitoring, battery health, roll-over sensing, and a fuel level sensor with improved accuracy and reliability were integrated and demonstrated

- The on-board monitoring system was hardened for field use and installed on two LAVs, including wheel drive planetary temperature sensing and planetary prognostics
- The two instrumented vehicles were field tested by Marines at Camp Pendleton.

3. Asset Health Management Software Development, Completed December 2004

Project Goal

Develop generalized software applications that provide for the collection, interpretation, and visualization of the health data generated by an Asset Health Monitoring system. The software should be generalized enough to allow the base software to be adaptable to a wide variety of different vehicle platforms.

NC3R developed software requirements from a combination of commercial and military platforms. Software applications were developed to: 1) collect sensor data and do on-board "real-time" data analysis, 2) synchronize vehicle data to a stationary maintenance server, and 3) provide maintainers the ability to view and analyze platform data by connecting to either the vehicle or maintenance server database. The software was deployed as a part of the LAVA HM system to Camp Pendleton.

User interface

Project Results

- Built and tested the core Asset Health Monitoring (AHM) Software that is designed to monitor the current health and usage of the platform, alert on abnormal conditions, provide diagnostic information, and store this data on the platform.
- Developed a Maintenance Data Synchronizer (MDS) that synchronizes the platform data to an off-board maintenance server using wired or wireless connectivity.
- Designed an application that maintainers can use to review and analyze platform anomalies and sensor data (Maintainers Graphic User Interface - MGUI). MGUI allows the user to obtain vehicle health and mission information from an on-board vehicle database or maintenance server and provides tabular and graphical summaries of platform data for individual vehicle missions or across multiple missions.

4. Hull Turret Optical Bridge Link Analysis for the Light Armored Vehicle, Completed July 2005

Project Goal

Develop a practical communications link for data transfer between the hull and the turret of the Light Armored Vehicle that does not significantly impact the current design.

NC3R investigated innovative ways to increase the communications bandwidth between the hull and turret in order to take full advantage of the AHM monitoring system and other emerging technologies. This link could provide a practical path to display in the turret

information that would allow the vehicle commander to monitor and interrogate an on-board monitoring system.

Project Results

- Completed a commercial, off-the-shelf survey and benchmarking of available communication technologies.
- Designed, built, and tested a proto-type of an optical communications link that could be fielded in the LAV 25 variant.
- Developed a protocol for a wireless CAN bridge and implemented the protocol with microprocessor based components

5. Common Operating Picture Development, Completed October 2005

Project Goal

Develop a web based application that provides a real time picture of the status of health and vehicle locations, providing both logisticians and operational commanders a common understanding of the battlefield. This common view should take full advantage of the data provided by the on-board AHM monitoring system to facilitate better informed decisions on vehicle mission assignment and also should improve the logisticians' capability to support and maintain the fleet. The system is intended to be used for demonstrations of autonomic logistics capability and is not intended to be an operational system.

NC3R worked with the PM-LAV and the Office of Naval Research to define high level requirements for a COP, particularly as applied to land vehicle assets. It was important to be able to rapidly demonstrate the system for a wide variety of global vehicle locations.

Project Results

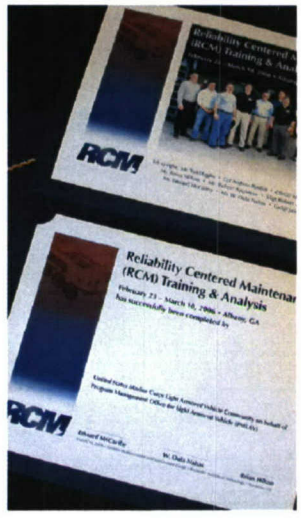
- Developed a Web based application using a commercial global mapping application (Google earth). This provided a major improvement in visual presentation and also flexibility for demonstrating in different locations over the original COP version.
- The mapping/tracking display links to second display which provides additional data on vehicle location, vehicle health and fuel state, and critical logistics parameters.
- The underlying database was also updated to allow for greater flexibility of use for multiple vehicles and types of vehicles.

6. Reliability Centered Maintenance (RCM) Certification of Facilitators, Completed November 2005

Project Goal

To develop RIT's expertise in Reliability Centered Maintenance by training facilitators, creating classroom material, maturing engineering processes, and developing software to facilitate RCM analysis.

RCM has been widely used in the commercial airline industry and the US Navy and there is increased interest in applications within the USMC. RCM provides a mechanism for improving the safety and efficiency of equipment operation and maintenance. It also provides a mechanism for identifying areas that proactive or CBM can be effectively applied. NC3R worked with industrial, educational, and DoD partners to develop an RCM program that could be effectively applied to military ground vehicle platforms. During this effort, NC3R staff was trained in an RCM process which is compliant with the SAE 1011 and 1012 standards for RCM application. In developing Asset Health Management capability for military platforms, RCM will be a driving factor in determining where sensors can be effectively applied for Condition Based Maintenance.



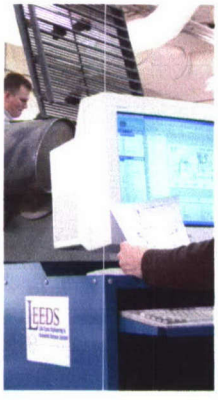
RCM training and certification

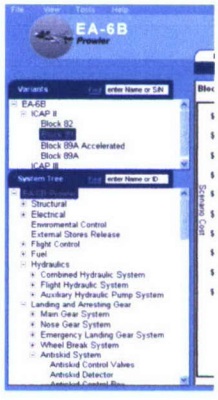
Project Results

- Trained internal staff to facilitate RCM Analyses.
- Developed SAE J1011/12 compliant RCM analysis software, with associated database and reports
- For process development, training, and software refinement purposes, RCM was successfully applied to an NC3R internal product

LEEDS®

Life-cycle Engineering and Economic Decision System





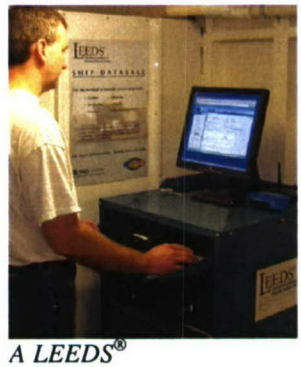
5. Life-Cycle Engineering & Economic Decision System (LEEDS®)

5.1. Description of Life-Cycle Engineering & Economic Decision System (LEEDS®)

In this era of austere budgets the Department of Defense is expected to improve its weapons systems readiness and effectiveness while reducing its Total Ownership Costs. The Department of Defense is employing an acquisition support strategy of Performance Based Logistics (PBL) in an effort to achieve these seemingly disparate goals. New economic concepts and supporting software is being developed to ensure that Program Mangers have the necessary means to provide for better system performance while reducing costs.

Life-Cycle Engineering and Economic Decision System (LEEDS®) is a "living" software tool applied to minimize total cost of equipment ownership and optimize system performance from design through retirement. It is designed to enable managers, maintainers, operators, and engineers to make intelligent maintenance, modernization, and remanufacturing decisions. The decision support system provides a consolidated source from which detailed information such as equipment condition and configuration histories, recapitalization metrics, and engineering design documents can be rapidly delivered to all platform stakeholders.

The Department of Defense faces many challenges in modernizing and maintaining its major systems. Even with recent budget increases, modernization and procurement budgets are considered far below levels needed for re-equipping the force, and operations and maintenance budgets for upgrade and conversion strain to keep existing systems operating with state-of-the-art capabilities. The military operations to combat terrorism in such harsh environs as Iraq and Afghanistan have greatly accelerated the aging of many of the critical weapons platforms and further exascerbated the problem for the Department of Defense. Furthermore, the long cycle times for major acquisition programs are hampering the Department's ability to efficiently and effectively modernize with technilgically advanced systems.



A LEEDS® implementation on a vessel.

Technology Gaps and Research Objectives

Ideally, major existing systems can be enhanced and new systems designed in a way that provides maximum readiness at minimum cost while reducing acquisition cycle times. Processes must exist to aid in the tough trade-off decisions that balance risk, product performance, cost, and cycle time considerations. Due to the complexity of the analysis, such

processes can benefit from computer assisted decision support tools that NC3R developed during this contract period.

In order to optimize modernization decisions, NC3R believes such processes should be integrated with system operations throughout the life cycle. This will not only allow the capture and storage of data critical to the decision process, but will also aid in the timing and implementation of remanufacturing/technology insertion cycles in order to minimize life cycle costs.

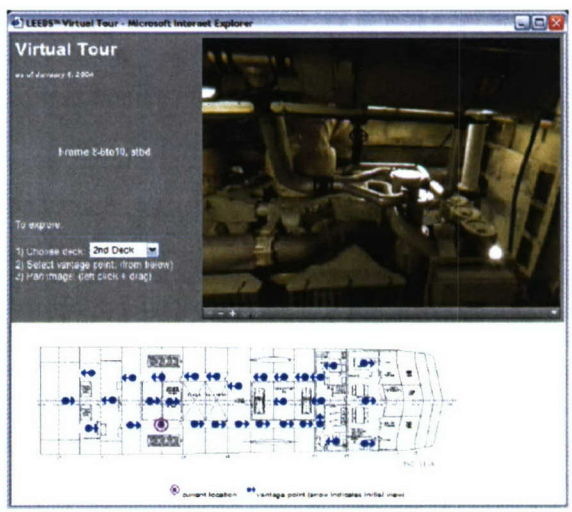
Life-Cycle Engineering and Economic Decision System (LEEDS®) is both an engineering process and a software tool that was refined by NC3R during this contract period to address this need. LEEDS® assists with decisions about the modernization, remanufacture, maintenance, and operation of large, complex systems.

LEEDS® was divided into three major initiatives based on where it is implemented within a system life-cycle and the number of platforms in the fleet:

- LEEDS®-R is the application of the process during remanufacturing, at system end-of-service. It encompasses an efficient technical and economic feasibility assessment process. This has been successfully piloted during this contract period and will provide the foundation for the continued development of the LEEDS® process and software tool.

- LEEDS®-D refers to the application of the process that commences during system design and continues to end-of-life. It allows global optimization of life-cycle costs through periodic remanufacturing/technology insertion feasibility assessment processes.

- Fleet LEEDS® - is the newest NC3R effort that focuses on helping Program Managers to maintain the readiness of their assets by assessing equipment recapitalization options by developing tools to aggregate equipment data and to analyze the impact of investment options across the fleet.



LEEDS® provides virtual tours.

Table 5.1 links the phases of development activities for LEEDS®. During this contract period, LEEDS® development for Phase I and Phase II has been conducted in collaboration with the Office of Naval Research, Lockheed-Martin Marine Systems, Naval Air Systems Command Electronic Attack Program Office, and USMC Light Armored Vehicle Program Managers Office and is reflected in the projects executed during this period.

Phase I Development	Phase II Development	Phase III Development
Maintenance support	Intelligent maintenance support	Portable HCI development
AHM diagnostic and prognostic systems	Platform performance monitoring	Fleet performance monitoring
Fleet recapitalization decision support	Advanced fleet decision support	Fleet monitoring and support

Table 5.1 LEEDS® Program Activities

The evolution of LEEDS® focused on improving an owner/operator's decisions relating to equipment life-cycle costs throughout system operating life, not only at end-of-life. This was achieved by positioning LEEDS®-D to serve as an efficient method for the identification, collection, and storage of pertinent system specifications from initial design and build activities. These specifications, in addition to the wealth of condition, performance, and cost data that accumulates during system life-cycles, is warehoused in a centralized repository and will allow LEEDS®-D to serve as an on-board maintenance support tool as well as a high-level performance monitor of key systems. This enables users to assemble and manage enormous quantities of design, cost, condition, and performance data. Performance and cost alternatives has been identified and updated easily by enabling users to frequently revisit maintenance, modernization, remanufacturing, operating costs, and other variables throughout the life of a system.

By providing the ability to compare competing options, the Department of Defense can make life-cycle decisions to meet the goals of lower operating costs, higher reliability and enhanced performance. With LEEDS®, the Department of Defense can easily review and analyze maintenance, modernization, and remanufacturing decisions.

The technology cycle for the LEEDS® process was based on the fact that much of the information that was helpful in remanufacturing a military platform was available in many disjointed data streams. The LEEDS® technology roadmap intended to combine this data and make it available for quick referencing inside one large structured database that was related to the functional hierarchy of the weapon system. The usefulness of the relational database drove the next technology effort of LEEDS® by making the database portable in a web based format for access by remote users. The web portal format has been designed to allow multiple program teams to call on the same data for reference, data storage, and retrieval and report development. As the functionality of the database grew with additional users, a more forward looking growth approach for data warehousing was envisioned which drove the technology shift away from the MS Access database and into a SQL database environment.

The SQL database affords greater security elements as well as the means to assign a date-stamp to items being entered into or deleted from the data architecture. Further, the technology roadmap introduced features for LEEDS® that allowed for synchronization between the primary database and disconnected databases. The means for a continuous data link could not be counted on so the LEEDS® development enabled two separated databases to be synchronized when a communications channel was available. Additionally, other

advances were made to enable group-based permissions in order to manage the allowable actions of distributed users accessing the portal.

The natural growth of the LEEDS® system would be the implementation of an automated condition monitoring package. The prognostic packages under development in the Asset Health Management program will reduce time consuming data collection needed when conducting condition assessments of pieces of equipment. Future development of LEEDS® will integrate decision support tools that enhance improvement trouble shooting efficiencies.

The aim of research during this contract period has been designed to build upon previous technology development efforts of both LEEDS® and the AHM program. Based upon the projects chosen and successfully completed during the last two years, much progress has been made toward the integration of these two programs that will result in the development of Platform Performance Monitoring and ultimately Fleet Performance Monitoring. The recapitalization decision support capabilities have already been expanded by extending the analysis of individual equipment to the analysis of an entire equipment fleet. The fleet decision support will be improved by incorporating advanced methods such as reliability centered maintenance analysis. Finally, maintenance support will be augmented by leveraging performance and reliability data to provide maintainers with more intelligent decision support tools.

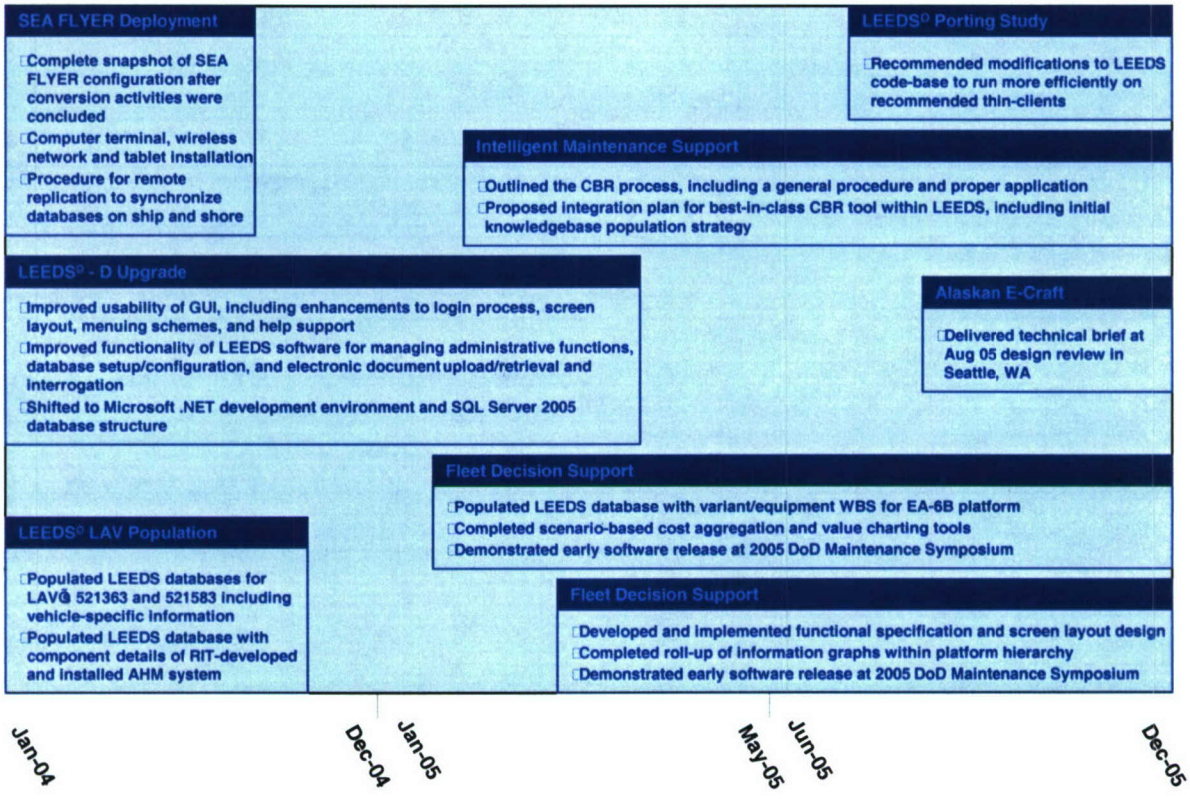


Figure 5.2. Primary LEEDS® Projects

5.2. Life-Cycle Engineering & Economic Decision System Projects

As shown in figure 5.2, the primary projects that were conducted under the LEEDS program include:

Ongoing Projects:

- Alaskan E-Craft Project
- AHM/LEEDS® Integration
- Fleet Decision Support

Completed Projects

- Deployment of LEEDS® Aboard ONR's SEA FLYER (July 2004)
- LEEDS® LAV Population Project (August 2004)
- LEEDS®-D User Upgrade (April 2005)
- LEEDS® Intelligent Maintenance Support (IMS) (December 05)
- LEEDS® Porting Study (December 05)

The projects are fully described in the next section.

Life-Cycle Engineering & Economic Decision Systems

PROJECTS

Life-Cycle Engineering & Economic Decision System Projects
Ongoing Projects

1. Alaskan E-Craft Project

Project Goal

To aide ship deployment and operation activities, LEEDS® will provide provisional documentation capabilities and engineering decision support during construction and service life. At a minimum, LEEDS® will serve as a provisional documentation repository for design and as-built data. At most, this effort will involve implementation of LEEDS® through inntegration with a ship-board monitoring system in order to capture and review equipment/ship health.

E-Craft is a program being funded by ONR and the State of Alaska to build a unique classification of naval craft. The craft will be used primarily by the Matanuska-Susitna Borough (MSB) as a fast ferry at the Knik Arm at Anchorage. Secondarily it is intended to be used by ONR as a variable-draft landing craft advanced technology demonstrator. Because of RIT's past experience with ONR, LEEDS® was chosen to provide the capability to capture design and construction artifacts in order to assist ship evaluation and service.

Project Results to date

- Attended the August 05 design review meeting in Seattle, WA, where a technical briefing of LEEDS® capabilities was delievered.
- Began process to establish a Proprietary Information Exchange Agreement (PIEA) with MSB in order to commence receiving ship data.

2. AHM/LEEDS® Integration

Project Goal

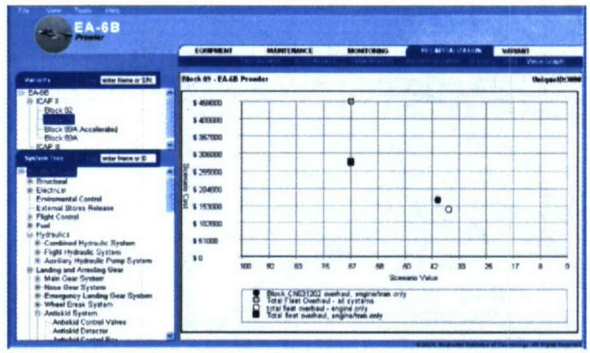
The integration of AHM and LEEDS® is designed to allow users to base decisions on performance, usage, and alert data being generated by a ground vehicle. Benefits of the integegration will include the ability to compare vehicle performance against previously collected data, the ability to quickly assess the operatioal readiness of the vehicle, and the ability to interrogate historical data at service life milestones.

For stakeholders, including program managers, engineers, and maintainers who require greater visibility of the operational status of their vehicles, the integration of AHM and LEEDS® will provide tools for assessing a vehicle's health from previous mission data. The tool will allow users to take advantage of historical data in addition to allowing functional analysis of vehiclar sub-systems. If problems are found, LEEDS® will provide the capability to interrogate system data surrounding the problem in order to provide further insight into the cause of the malfuction or warning.

Project Results to date

- Developed evaluation approach and criteria for graphing/charting software for integration with .NET development environment.

- Implemented Phase I functional specification and screen layout design.
- Completed roll-up of information graphs within platform hierarchy.
- Demonstrated early software release at 2005 Defense Maintenance Symposium.



LEEDS® for the EA-6B Prowler

3. Fleet Decision Support

Project Goal

This project seeks to extend the proven technical and economic decision support provided by LEEDS® to assess equipment recapitalization options, by developing enhanced tools to aggregate equipment data and to analyze the impact of investment options across the fleet.

In collaboration with various program manager offices and including aviation and ground vehicles, variant and equipment data will be collected and populated within LEEDS®, reflecting platform work breakdown structures (WBS). Customer requirements will be solicited from the program manager offices to investigate and develop platform configuration management and fleet economic decision-making methods, augmenting life-cycle engineering decision system capabilities. The resulting methods will be implemented in the LEEDS® software tool to demonstrate their capability in evaluating recapitalization scenarios within a fleet context.

Project Results to date

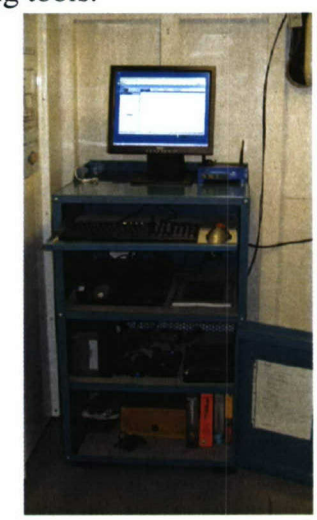
- Populated LEEDS® database with variant and equipment WBS for the EA-6B platform.
- Completed testing/debugging and demonstrated early software release at 2005 Defense Maintenance Symposium.
- Completed scenario-based cost aggregration and value charting tools.

Completed Projects

1. Deployment of LEEDS® Aboard ONR's SEA FLYER, Completed July 2004

Project Goal

Develop and deploy a LEEDS® database on the SEA FLYER advanced technology demonstrator (ATD,) reflecting new ship configuration to be used by ship's personnel in support of sea-trials and general operation and maintenance of ATD.



LEEDS® computer terminal on SEA FLYER

Conversion of the SES-200 to the SEA FLYER hull-form required significant modifications to ship systems and structure. As a

continuance of previous work completed under the Remanufacture and Conversion SES-200 project, a LEEDS® database was constructed to reflect the new ship configuration. Engineering drawings, systems schematics/manuals, component specifications, and acquisition/ vendor information was assembled, linked, and archived. A computer network was installed on the ship to allow the crew access to the data.

Project Results

- Developed a complete snapshot of SEA FLYER configuration after conversion activities were concluded.
- Installed computer terminal, wireless network, and tablet to allow maintainers access to database throughout the ship's engineering spaces.
- Set up a procedure for remote replication to synchronize databases on ship and shore.

2. LEEDS® LAV Population Project, Completed August 2004

Project Goal

In support of the LEEDS®-D User Upgrade project and Asset Health Management program development, undertake an effort to fully populate a LEEDS® database for the LAV-25 platform.

Securing access and collecting quality data to be populated in LEEDS® is a significant undertaking. By taking advantage of the fortune of temporarily housing several LAV-25s at the RIT facility, a project team documented vehicle systems and populated a LEEDS® database with articles such as equipment model numbers, pictures, conditions, drawings, manuals, and failure modes. Additionally, component details of the RIT-developed AHM system installed on the LAV were also documented.

LEEDS® can be applied to a variety of platforms

Project Results

- Populated LEEDS® databases for LAVs 521363 and 521583; including vehicle-specific information such as equipment configuration, model numbers, and conditions.
- Populated LEEDS® database with compontent details of RIT-developed AHM system installed on LAVs.

3. LEEDS® Intelligent Maintenance Support (IMS), Completed December 2005

Project Goal

Case-based reasoning (CBR) is a form of knowledge management that utilizes past experience in order to guide users to problem resolution. It is the expectation that integration of CBR software tools with LEEDS® would be able to leverage existing data to provide

significant maintenance support functionality. It was the goal of this project to benchmark existing CBR software and evaluate integration within LEEDS®.

Case-based reasoning (CBR) is an approach to problem solving and learning that has been seen as a technology that could benefit LEEDS®. It is commonly used for applications such as maintenance/diagnostic aides and customer call-centers. Being that LEEDS® is primarily a recapitalization decision support tool to be used by owners and engineers, a variety of data is acquired and retained through equipment life in order for the decision process to work effectively. Much of this data is useful to equipment operators and maintainers in the fulfillment of their jobs. As a result, LEEDS® has been designed to also support use by maintainers. This project involved the investigation of CBR philosophies, identified and reviewed commercially available software tools, and examined the feasibility of integration within LEEDS®.

Project Results

- Outlined the CBR process, including a general procedure and proper application.
- Identified top three CBR software tools out of ten.
- Proposed integration plan for best-in-class CBR tool within LEEDS®, including initial knowledge base population strategy.

4. LEEDS® Porting Study, Completed December 2005

Project Goal

Maintainers, operators, engineers and managers commonly use smaller, hand-held devices when performing their jobs. The purpose of this study was to evaluate smaller devices and examine the feasibility of running LEEDS® on such devices.

This was done by examining changes to LEEDS® to make it easier to use in small devices, and by examining the feasibility of using speech recognition software, wearable computers, and head-mounted displays in conjuction with the LEEDS® graphical user interface. Such devices investigated included: tablet computers, handheld computers, smartphones, wearable computers, and head-mounted displays.

Project Results

- Completed a comprehensive benchmark of small form-factor computers.
- Investigated software involved to support, including operating systems and voice-recognition technologies.
- Defined use-cases describing the hypothetical interaction of several hardware/software solutions.
- Recommended modifications to LEEDS® code-base to run more efficiently on thin-clients.

Technical users gain quick access to critical manuals and drawings that are integrated within LEEDS®.

5. LEEDS®-D User Upgrade, Completed April 2005

Project Goal

A major evolution of the LEEDS® tool was necessary in order to meet user requirements identified during early applications of the software tool. This development project resulted in a major upgrade in the technology and capability of the decision tool.

Much of the information used at end-of-life is useful, and in many cases more readily avaiable, for decisions made *during* a platform's life. Significant development was necessary to support the transition of LEEDS® from its original purpose, as an end-of-life recapitalization tool, into an entire life-cycle support tool to be initiated at platform design. Key technology improvements were made to configuration management, digitial document management, interface usability, data accessibility and security, and underlying database structure.

Project Results

- Improved usability of user interface, including enhancements to login procedure, screen layout, menuing schemes, and help support.
- Improved functionality of LEEDS® software for managing administrative functions, database setup/configuration, and electronic docoment upload/retrieval and interrogation.
- Eliminated 3rd party software components so that client-side software plug-ins were no longer necessary.
- Improved modular design of code which included shift to Microsoft .NET development environment and SQL server 2005 structure.

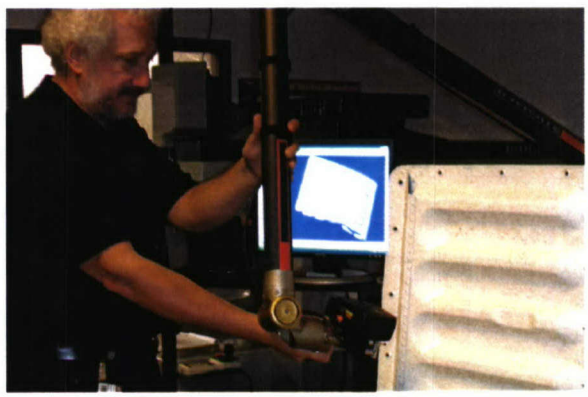
Material Aging

6. Material Aging

6.1. Description of Material Aging

The Department of Defense is facing severe challenges surrounding the maintenance of older legacy platforms along with the accelerated aging of new systems due to the Global War on Terrorism. All of this will require new technologies and techniques in times of shrinking budgets and increasing demand. Through a robust material aging program, RIT's National Center for Remanufacturing and Resource Recovery (NC3R) is developing practical, cost-effective means to keep equipment operating longer and more reliably. Thus allowing Program Managers the means to navigate the balance between budget concerns and aging defense equipment.

Material aging is a process that over time changes the physical appearance, dimensions, or physical or mechanical properties of a component and is the principal cause for the reduction of reliability and margin of safety for engineering systems. When components are placed into service, they begin to "age" because of exposure to environmental factors such as elevated temperature, ultraviolet radiation, moisture, impact, or sliding.



Digital data capture using laser scanner

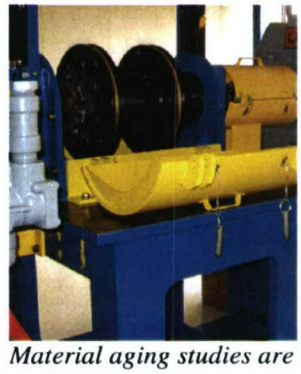
During the material aging process, a system's components, over time, may change their appearance, dimensions, or physical and mechanical properties. NC3R's Material Aging program, during this contract period, focused on the development of several interacting technologies including: laboratory inspection techniques using non-destructive inspection methodologies; aging and failure propagation models for crucial mechanisms including fatigue, wear, and corrosion; and the prediction of remaining life (prognostics) for essential system components. Current efforts using these technology sets are focused on prognostics for combined gear and bearing systems, development of cost-effective component restoration methods, reverse engineering of aircraft structural component, and testing of aircraft hydraulic systems.

Material aging research is the key to understanding part and equipment failures. It advances the understanding of how materials age and how they fail. The technology developed through this work effort contributed to advances in the application of tools and methods that predict the equipment's future maintenance needs and remaining useful life.

The EA-6B, one of the aviation platforms that has benefited from the work under this contract, has as its primary mission to protect strike aircraft by jamming hostile radars and communications and to direct attack of radiating threat radars employing the HARM missile. When the DoD restructured its assets in 1995, retiring the EF-111 Raven, the EA-6B was left as the only radar jammer in the Department of Defense inventory.

The Navy's EA-6B Prowler, an electronic warfare (EW) platform

The EA-6B Prowler is undergoing structural renovations to increase its service life. To combat metal fatigue and improve the plane's performance envelope, the EA-6B is being refitted with a new central wing section. In a related program, Strike's Prowler test group recently completed testing of the structural data recording system (SDRS) to monitor fatigue in the airframe and help extend aircraft life expectancy. Although the Prowler is aging and has been identified for eventual replacement, it is slated to stay with the fleet through 2015.



Material aging studies are applied to LAV planetaries

The Light Armored Vehicle-25 (LAV-25) is an all-terrain, all-weather vehicle with night capabilities that has benifited greatly from the work during this period. It provides strategic mobility to reach and engage the threat, tactical mobility for effective use of fire power, fire power to defeat soft and armored targets, and battlefield survivability to carry out combat missions. The life cycle of this platform is being extended by 20 years and the problems encountered with these vehicles are not only corrosion and fatigue but wear as well. NC3R Material Aging research has focused on ensuring that this crucial equipment is not rendered ineffective by age. Through this effort, a greater insight into material aging was gained and has been the key to effectively and reliably extending the life of these important assets.

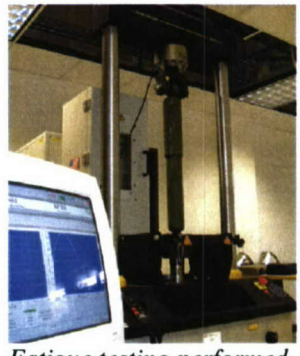
Technology Gaps and Research Objectives

The ongoing NC3R research program evaluates, develops, and applies material aging technology to increase the useful life of either existing or new component or system designs and to develop cost-effective material salvage techniques for "worn" components.

- NC3R has used the Physics of Failure Method to study the material aging process. In this process, a root cause failure analysis is performed first, using optical and scanning electron microscopy techniques, to determine the material aging mechanism on a macro or microstructural level. Then, using computer aided simulation the failure mechanism is replicated. Finally, the simulation is verified using laboratory tests and components or subassemblies designed to replicate the aging mechanism.

Based on these methodoligies NC3R has developed several material aging capabilities during this contract period. They include:

- Structural health monitoring or condition assessment
- Material based prognostics
- Restoration



Fatigue testing performed on a LAV shock

Condition assessment understands which material aging mechanism is present and the extent to which the aging has affected the function and physical and mechanical properties of the component.

Material based prognostics is used to determine the remaining life of a component that has undergone material aging. These prognostics are obtained by initally simulating the material aging mechanism in the laboratory and then verifying it by running components or simulated components to failure.

The ability to predict the time to failure, on a real time basis, benefits asset health management systems and has the potential for reducing overall life cycle costs. NC3R is using material based prognostics to generate predictive models from simulated laboratory testing and fault propagation. This prognostic development uses component or subassembly testing and is verified using subscale or full scale systems.

Signature analysis is concerned with the analysis of signals obtained from subassemblies or components. It is a diagnostic technique where certain parameters from a set of characteristic signals are extracted when operating a particular device. These parameters can provide useful information about the "state of health" of the device.

Material restoration brings back a component that has been in service back to a pristine, like-new condition. A restoroation technique is selected after a root cause failure analysis has identified the material aging mechanism. Understanding of how the component failed enables the proper restoration technique to be selected. It will also enable a technique to be selected that will improve the performance of the component by providing increased resistance to the material aging mechanism. For example, if the material aging mechanism identified is corrosion, a material restoration technique can be selected to have improved corrosion resistance over the original material.

Through the understanding of material aging and the utilization of the above capabilites, NC3R has accomplished the following:

- The insertion of design or material changes to increase the relibility and life of a component or system.

- The development of material restoration techniques to increase the useful life of components by restoring them to an "as new" condition.
- The prediction of the remaining life of the component or system.

During the contract period, NC3R applied these capabilities to the flaperon actuator and planetary drive systems on the EA-6B aircraft and the LAV-25 respectively.

Through testing conducted at the NC3R facility, fatigue was identified as the root cause for the failed flaperon actuators. Finite element modeling was then used to create a solution which was verified using laboratory simulation. The recommendation for extending the life of the actuator was to change the thread design for the end cap and change the procedure used to clean the actuators when rebuilding them. These changes have been adopted by NADEP Jacksonville.

To analyze the operation of the LAV-25, NC3R developed and installed temperature and vibration sensors installed on the vehicle's planetary drive. The system successfully "monitored the health" of the drive and assisted engineers in identifying issues with the component.

Based on the data provided, a root cause fauliure analysis of failed LAV planetaries identified the failure mechanism and a laboratory bench test has been designed and built to simulate this failure. The results of this testing have identified a potential solution that could extend the life of the drives.

In addition, the feasibility of implementing a new, non-destructive technique that utilizes reflected light to identify the amount of material aging encountered by the surface of a component during use has been successfully demonstrated on flat surfaces. This procedure can eventually be used to predict the remaining life of wear surfaces.

Table 6.1 shows the capabilities and enabling technologies developed to support the Material Aging Program during this contract period.

Capabilities	Enabling Technologies
Structural Health Monitoring (Condition Assessment)	Damage Detection (Nondestructive Inspection)
Material Aging Prognostics	Structural/Analytical Analysis
Restoration	Signature Analysis
	Root Cause Failure Analysis
	Fault Propagation (for Predictive Models)

Table 6.1. Material Aging Capabilities and Enabling Technologies

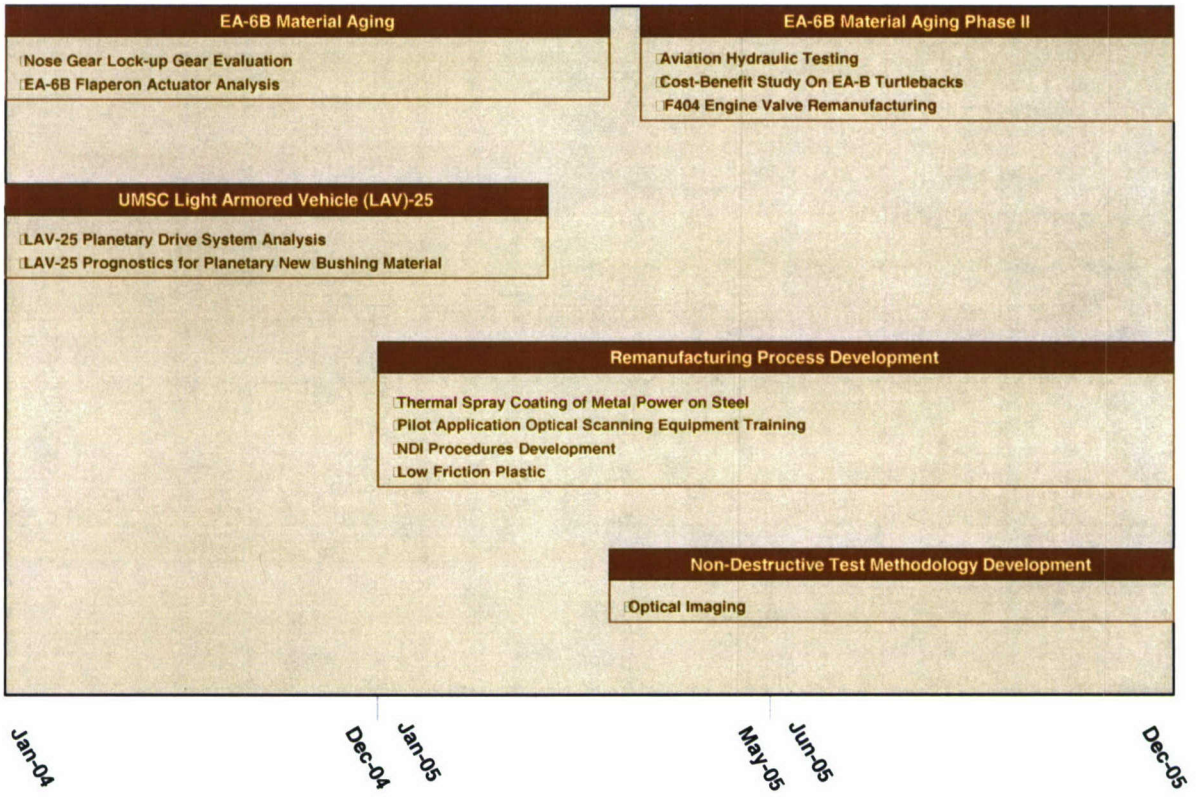
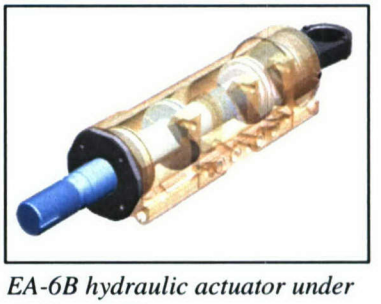


Figure 6.2. Primary LEEDS® Projects

6.2. Material Aging Projects

The Material Aging program funded by this contract is enhancing NC3R's technical capcity and supporting numerous DoD programs and platforms. The Material Aging program focused on understanding material aging and applying this knowledge to structural health monitoring, component restoration, and material based prognostics. The technologies developed include finite element analysis for structural modeling (EA-6B landing gear uplock), fatigue life prediction (EA-6B Hydraulic Actuator), applying signature analysis techniques (Signature Analysis and Prognostic Development for LAV Planetary), root cause failure analysis (Prognostic Development for LAV Planetary, EA-6B Hydraulic Actuator), and solid modeling (EA-6B Hydraulic Actuator and EA-6B Turtleback Remanufacturing).



EA-6B hydraulic actuator under study at RIT

Ongoing Projects:

- EA-6B Material Aging Phase II
  - Aviation Hydraulic Testing
  - F404 Engine Valve Remanufacturing
  - EA-6B Turtleback Reverse Engineering
- Non-Destructive Test Methodology Development
  - Optical Imaging
- Remanufacturing Process Development
  - Thermal Spray Coating of Metal Power on Steel
  - Pilot Application Optical Scanning Equipment Training and NDI Procedures Development
  - Low Friction Plastic

Completed Projects:

- EA-6B Material Aging
  - EA-6B Nose Gear Lock-up Evaluation (May 2005)
  - EA-6B Flaperon Actuator Analysis (September 2004)
- Material Aging Light Armored Vehicle
  - Light Armored Vehicle: Planetary Drive Systems (June 2005)
  - Prognostics for Light Armored Vehicle Planetaries New Bushing Material (March 2005)

The projects are fully described in the next section.

Material Aging

PROJECTS

Material Aging

Ongoing Projects

1. EA-6B Material Aging Phase II Projects

Hydraulic System Pressure Variation

Project Goal

To determine the effect of extending wing flaps, slats, landing gear and tail hook on hydraulic line pressure and flow

NC3R is working with NAVAIR to determine the cause for hydraulic leaks that occur when the wing flaps and stabilizers, landing gear, and tail hook are extended. This is accomplished by using an A-6E aircraft at NC3R and actuating the remote systems with the plane on the ground.

Project Results to Date:

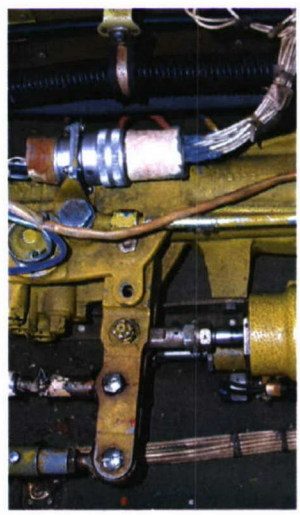
- Developed report that summarizes the effect of extending the flaps, stabilizer, landing gear, and tail hook on hydraulic pressure flow and temperature.
- Identified locations where any hydraulic leaks occurred.

F404 Engine Valve Remanufacturing

Project Goal

The project goal was to first summarize the root cause failure analysis results and then present several remanufacturing options for the electrohydraulic servo valve.

The F404 Fan Variable Geometry (VG) actuator (Part Number 5033T53P03) is a high value component that is currently being scrapped by the depot when the valve can no longer be adjusted to its null value. The F404 Fan Variable Geometry (VG) actuator (Part Number 5033T53P03), is used on all FA-18A, B, C, and D aircraft operating the F404-400 and 402 engines. The actuator provides an output force and motion to a variable fan stator system. This system is used during both normal engine operation and when missiles are fired from certain wing positions to reduce the potential of an engine stall.



Rudder Actuator EA-6B

Project Results to Date:

- Identified root cause for the actuator not fully stopping at the null.
- Developed a potential method for remanufacturing the servo valve.

EA-6B Turtlebacks Reverse Engineering

Project Goal

Perform a cost benefit study to determine the best options for providing the Navy with additional EA-6B Turtlebacks

NC3R is working with NAVAIR to determine the best options for providing the Navy with additional EA-6B aft turtlebacks. Remanufacturing existing turtlebacks was eliminated because the condition of the existing EA-6B or A-6 turtlebacks required significant rework which would increase the remanufacturing costs significantly. The best option was to fabricate new turtlebacks using a modified design that was easier to manufacture and less susceptible to corrosion.

Deliverables:

- New mid-turtleback design that is less expensive to produce and has improved corrosion resistance
- Two flight ready turtlebacks

2. Non-Destructive Test Methodology Development

Optical Imaging

Project Goal

The objective of this study was to determine if optical imaging techniques can detect wear and corrosion on steel and aluminum components.

Modern high resolution digital cameras can facilitate the capture of an image encompassing a relatively large area and high speed computing systems can quickly process that image, yielding metrics that relate to the surface being examined. In addition, as imaging techniques are non-contact and require minimal setup, the eventual automation of inspection processes becomes more feasible. This will result in increased productivity and reduce reliance on highly trained operators. As NDI imaging techniques are "trained," estimations of the remaining life for a part will become more feasible.

A number of imaging technologies have the advantage of being capable of examining relatively large areas. While these techniques may lack the fine detail of some micro-scale techniques, observations made on a macro-scale can be correlated to micro-scale phenomena.

Project Results to date

- Built a fixture that can measure the optical reflectance of a surface over a wide range of angles.
- Obtained a preliminary relationship between the surface roughness and optical reflection.

3. Remanufacturing Process Development

NC3R is working with the PM-LAV Office and USMC Maintenance Facilities to identify subassemblies or components that are candidates for remanufacture. Once subassemblies or components are identified a process for remanufacturing these components or subassemblies will be developed and demonstrated.

Remanufacture of LAV Drive Shafts

Project Goal

Determine remanufacturing processes for LAV drive shafts currently being scrapped

The objective for the LAV drive shaft remanufacturing project was to develop an alternative process to recoat the outside surface of existing LAV drive shafts. Each LAV drive shaft costs approximately $750. Presently, these shafts are being discarded once one of the following happens:

- The seal on the female and male mating surface becomes damaged.
- The nylon surface coating wears, allowing rust, dirt, water, etc. to negatively effect operation.

Successful development and implementation of an LAV drive shaft recoating process would result in a far more cost effective process; saving up to 700 dollars per shaft.

In addition to the LAV drive shaft recoating study, NC3R developed a seal replacement process. The existing seals used in the drive shafts are no longer manufactured. Therefore, NC3R worked with an outside company to manufacture appropriate seals for the LAV drive shafts.

Project Results to Date:

- Produced report detailing a remanufacturing process for a LAV driveshaft
- Transferred remanufacturing process to Albany and Barstow Depots
- Identified manufacturer for drive shaft seals

Applying coating to a drive shaft

Completed Projects

1. EA-6B Material Aging Projects

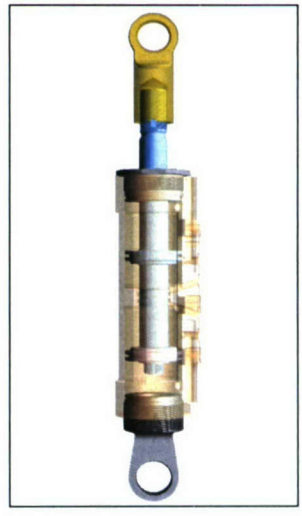
EA-6B Nose Gear Lock-up Evaluation, Completed May 2005

Project Goal

NAVAIR requested RIT to perform a Finite Element Analysis (FEA) on the EA-6B Uplock Support Bracket.

Several failures have occurred on the EA-6B Uplock Support Bracket and NAVAIR requested that a Finite Element Analysis be performed to determine design or material changes that could prevent these failures. The static finite element analysis evaluated the nose gear configuration and sequence of operation to determine worst case loading, load location, and direction using:

- Load values based on capacity of Nose Gear Actuation Cylinder
- Properties for 2014-T4 Aluminum Alloy (yield = 40 ksi, E =10.6 x 106 psi)



EA-6B flaperon actuator analysis

Project Results:

The results of the finite analysis were:

- Cylinder Retraction resulted in highest stresses and most widespread areas of overstress
- Stress Distribution showed highest stresses in the bottom flange, door crank mechanism support, and vertical stiffeners
- Design criteria, in-service load data, and failed parts are needed to perform a more in-depth evaluation

EA-6B Flaperon Actuator Analysis, Completed September 2004

Project Goal

Determine the root cause for the fatigue failures of the flaperon actuator and determine a method for extending the life of this component.

Several fatigue failures of the EA-6B flaperon actuator have occurred. NC3R supported the EA-6B engineering team by modeling the flaperon actuator to determine the reason for the fatigue failures. The model was then verified by simulation testing. Using both the model and simulation results, recommendations were made to increase the life of the flaperon actuator.

Project Results:

- Delivered recommendations for a design change and a new cleaning process to increase the fatigue resistance of the flaperon actuator
- NADEP Jacksonville has adopted both recommendations

2. Material Aging Light Armored Vehicle

Planetary Drive Systems, Completed May 2005

Project Goal

Determine reason for planetary drive to run at elevated temperatures.

NC3R worked with the PM-LAV Office to quantify the root cause for planetary drive systems on LAVs to run at higher temperatures than other similar planetary drives. The elevated operating temperatures cause these planetary drives to fail.

Project Results

- Identified the root cause for the planetary drive systems running at elevated temperatures
- Developed an option to reduce the operating temperatures of planetary drive systems

Prognostics for Light Armored Vehicle Planetaries New Bushing Material, Completed March 2005

Project Goals

The project goal was to evaluate a new bushing material for the LAV planetary.

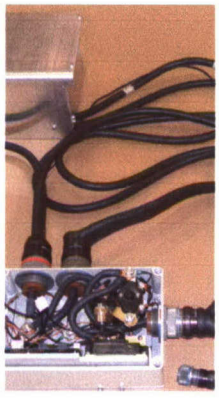
A root cause failure analysis performed at NC3R on a failed planetary showed that the reason for the planetary "lock-up" was the bushing had softened and was extruded from the planetary gear assembly. The extruded planetary bushing then flowed between the planetary gear and carrier plate preventing the planetary gear from rotating and "locking-up" the planetary drive. If the bushing can be replaced with a bushing with improved temperature and load bearing capability the operability of the LAV planetary drive will be improved.

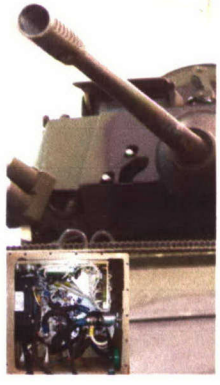
Project Result

- A final report was issued summarizing the testing and recommendations by NC3R.

MTRAC

Modernization Through Remanufacturing and Conversion





7. Modernization through Remanufacturing & Conversion (MTRAC)

7.1 Description of MTRAC

As the United States continues to be a leader in global peace, it is apparent that our future forces are going to be using older equipment for longer periods of time. A balance must be realized between declining budgets and the need to revitalize our aging equipment in order to provide advanced technology insertions into front line weapon systems. Unlike most firms in the private sector, the many branches in the Department of Defense (DoD) manufacture, consume and maintain many of its own systems. Rapid advances in technology and ever shortening system life-cycles demand quick response times for conversion and/or upgrades of existing systems.

Modernization through Remanufacturing & Conversion - One of the answers to modernizing our defense resources while working with a shrinking funding source is through a practice known as remanufacturing. Remanufacturing is a highly effective strategy of restoring used durable products to a "like new" condition, while enabling technology upgrades, at a substantial savings to the end user.

Modernizing systems by applying remanufacturing principles is the key to fielding new technologies at low cost and low risk along with improved performance and shorter lead-times. Operating costs and environmental costs can be kept low by modernizing legacy systems instead of purchasing new systems outright. Additionally, through selective approaches in remanufacturing, improvements will be garnered in the reliability, availability, and maintainability (RAM) of systems. This cost-effective way of producing new military platforms can minimize the costs of modernization and upgrades. It satisfies technology needs at critical moments while reducing lead times for procuring new systems. Modernizing existing systems through remanufacturing is a way to maximize yesterday's investments tomorrow. By making equipment contribute more value for longer; it insures the investment by providing a way to test technologies before investing in them.

During the contract period, the National Center for Remanufacturing and Resource Recovery (NC3R) has been conducting ongoing research to develop technologies to modernize equipment through remanufacture and conversion. MTRAC is an organized approach for integrating remanufacturing into the full life-cycle of a product or system. The MTRAC program has developed tools and processes to aid in design for remanufacture, remanufacturability assessment, cost estimations for upgrades, and

advanced technology insertions. This program has delivered to ONR cost-effective, superior techniques to assist in upgrading, converting, and maintaining a system once it is deployed.

NC3R uses a unique combination of expertise in analysis of material failures, analysis of structural integrity and performance, diagnosis of product health and prediction of remaining life, and end-of-life recovery to help the Department of Defense manage their deployed asset investments. The MTRAC innovative approach to the life-cycle of a product emphasizes the importance of improving RAM issues that would normally plague legacy platforms.

Since many systems employed by the DoD are costly to manufacture and maintain, strategies to reduce these costs have the potential to conserve significant financial resources. Remanufacturing is a powerful approach to sustaining and advancing technological systems. It is often conducted through a series of steps, including disassembly, cleaning, inspection, refurbishment, technology upgrade, assembly, and testing to original or enhanced specifications. Often, remanufactured systems are upgraded with the advanced features of today's equipment.

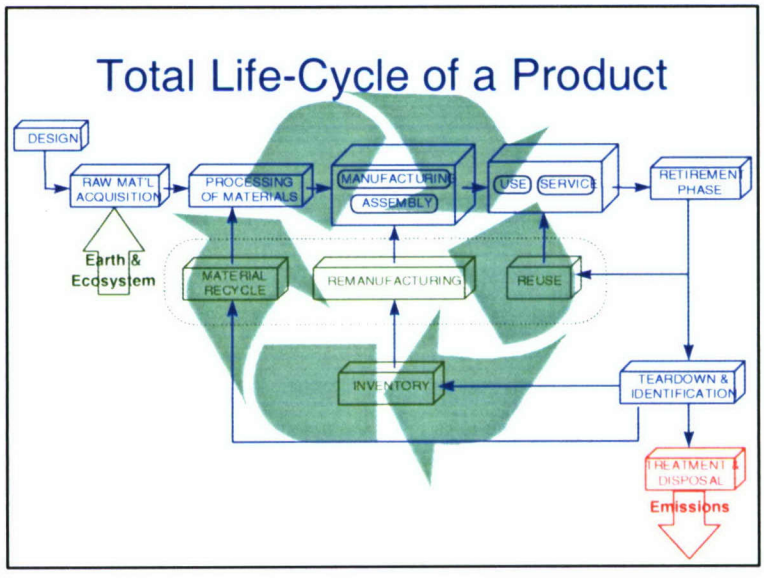


Figure 7.1 – Life-Cycle of Systems/Equipment

Remanufacturing serves a strategic goal for satisfying technology needs at critical moments while reducing lead times of procuring new systems. It also does not require the same resources needed for the manufacture of new systems, so remanufacturing operations can be done much closer to the system's point of use. Unlike recycling, where only the material value of a product is recovered, remanufacturing captures the material

value as well as the labor and capital investment of value-added operations that took place during original production.

Technology Gaps and Research Objectives

In order for a product to be remanufactured in the best possible manner, it needs to be designed for remanufacture from the start. A number of design strategies have been developed to facilitate remanufacturing during this contract. They include: avoidance of permanent fastenings such as welding or crimping; making designs modular so that assembly/disassembly times are minimized; and standardizing fasteners to reduce assembly/disassembly and material handling complexity.

Remanufacturing can be thought of as a single stage of the life-cycle of a system or piece of equipment, as depicted in Figure 7.1. Operations can be made more efficient through the use of support technologies and methodologies. For example, reverse engineering techniques were used to generate original equipment design specifications and tolerances when this information was unavailable at the remanufacturing stage in direct support to a number of fleet customers, including the Program Management Office for the Light Armored Vehicle and the EA-6B, and F-18 Naval Aviation Program Managers. Design capture can be utilized to collect information from equipment at end-of-life and feed back improvements to the design process. Life-cycle costing methodologies can support intelligent design selection by uncovering cost information up to and including system end-of-life and is reflected in a number of our direct support projects.

Modernization through Remanufacturing and Conversion provides the tools that can be applied to the remanufacture of ships, aircraft, tanks, trucks, and a variety of other vehicles, platforms, and equipment. MTRAC provides a method for the procurement of products that meet or exceed new product standards, incorporate technological advances and reduce the total system cost.

A remanufacturing process was developed and implemented on the SES-200 vessel, owned by the Office of Naval Research. This process was developed in two parts to evaluate separately the engineering and economic feasibility of the project.

The engineering feasibility, as shown in Figure 7.2, collected data on the platform, then through a functional analysis, condition assessment, failure mode effect and criticality study, and review of the forward going operational specifications provided the available remanufacturing options.

The process of balancing each of these inputs to derive the appropriate remanufacturing option assessment has evolved into an algorithm based application.

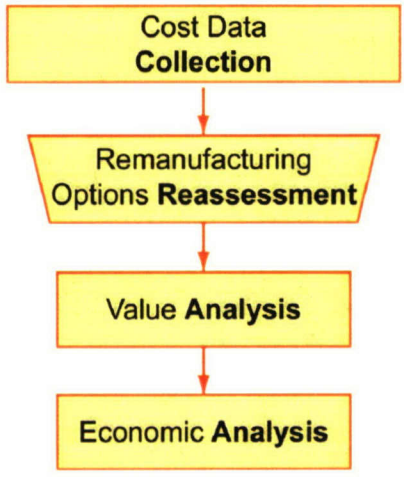


Figure 7.2 Engineering Feasibility

The next part in the remanufacturing tool is a careful examination into the cost structure for each of the potential "remanufacturing options" as determined in the engineering feasibility section. The economic feasibility would follow the process as illustrated Figure 7.3.

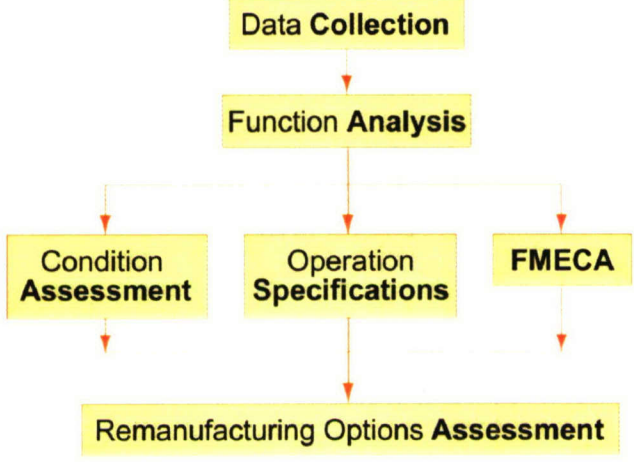


Figure 7.3 Economic Feasibility

Each of the potential remanufacturing options would have a cost determination developed to place that specific part into like new condition. The cost determination for each option would be compared against one another in a value analysis which would allow the equipment users to weight what factors were more important or less important to them.

Some of the factors studied in the NC3R project included: life expectancy, consumable cost, acquisition cost, and environmental impact. The weighting of these factors would be used as an input to the economic analysis which would combine the cost determination with the value analysis weights and determine the most appropriate remanufacturing option. The best remanufacturing options are then rolled up on each component to create the overall cost to remanufacture the platform. By applying these processes to the SES-200 vessel the Office of Naval Research was able to calculate the expected cost outlays to return the ship to a like new condition.

The aim of our research during this contract period, as reflected in a number of our projects, has been to apply the elements of MTRAC towards target customers with aging equipment to provide real value in terms of increased capability, longer life, less maintenance, and decreased costs.

NC3R Project Detail: Modernization Through Remanufacturing & Conversion (MTRAC)
ONR Grant N00014-03-1-0860

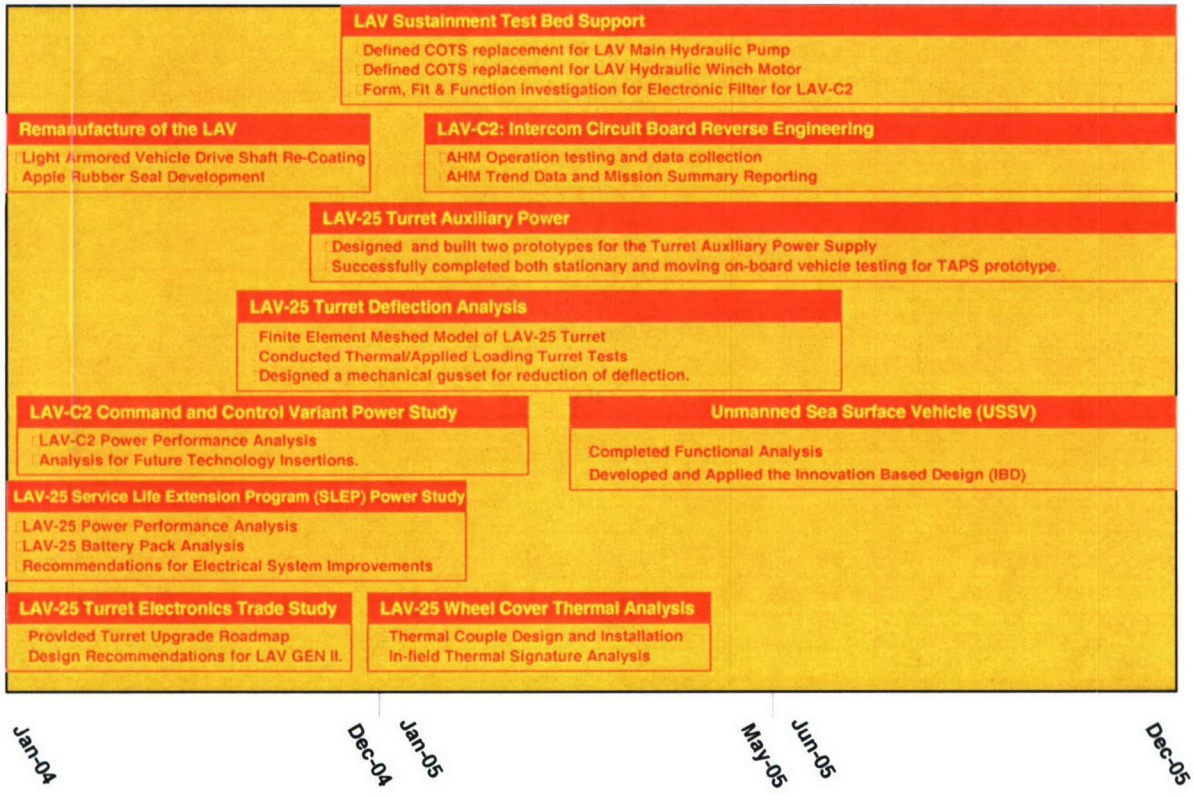


Figure 7.4 Primary MTRAC Projects

7.2 MTRAC Projects

As shown in figure 7.4, the primary projects that were conducted under the MTRAC program include:

Ongoing Projects:

- Sustainment Test bed 339 Support
- Light Armored Vehicle: Intercom Circuit Board Reverse Engineering,

Completed Projects:

- Remanufacturing of Light Armor Vehicle
  - Light Armored Vehicle Drive Shaft Coating Development (July 2004)
  - Apple Rubber Drive Shaft Seal Development for Light Armored Vehicle (April 2005)
- Light Armored Vehicle: Turret Electronics Trade Study (November 2004)
- Light Armored Vehicle Wheel Cover Thermal Signature Analysis (December 2004)

- Light Armored Vehicle Command and Control (C2) Variant Power Study
- (February 2005)
- Light Armored Vehicle Service Life Extension Program (SLEP) Power Study (February 2005)
- Light Armored Vehicle Turret Deflection Analysis (April 2005)
- Light Armored Vehicle: Turret Auxiliary Power System (November 2005)
- USSV Functional Analysis and IBD (December 2005)

The projects are fully described in the next section.

Modernization Through Remanufacturing and Conversion

PROJECTS

Modernization through Remanufacturing & Conversion

Ongoing Projects

1. Light Armored Vehicle: Sustainment Test bed 339 Support

Project Goal

Developing technology solutions and testing/verifying alternative sources of commercial supplies for the sustainment support of Marine Corps Ground Combat Light Armored Vehicle.

The Marine Corps Light Armored Vehicle has been extended past the originally planned operational life and as such the PM-LAV office has experienced increasing difficulty in obtaining the replacement parts that are needed to maintain its capability. LAV stakeholders submit to PM-LAV the Defense Logistic Agency Form 339s for reporting engineering and technical issues that inhibit the acquisition of correct supply items. NC3R will periodically provide technical engineering expertise to the PM-LAV in order to present solutions for procuring material in a timely manner for direct support of service warfighters.

Project Results to date:

- Investigation of Commercial-off-the-Shelf replacement for Light Armored Vehicle main hydraulic pump.
- Investigation of Commercial-off-the-Shelf replacement for Light Armored Vehicle Hydraulic Winch Motor for the LAV-R variant.
- Investigation of Commercial-off-the-Shelf replacement for Light Armored Vehicle Hydraulic Solenoid Valve for the LAV-AT variant.
- Form, fit, and function investigation for the Electronic Filter for the JV-2805 Communications System for the LAV-C2 variant.

2. Light Armored Vehicle: Intercom Circuit Board Reverse Engineering

Project Goal

Reverse engineer critical circuit boards from the LAV Command and Control variant intercom and provide first engineering samples and detailed design data

Critical circuit board components of the LAV-C2 intercom control box cannot be procured by PM-LAV as a complete design package is not available. The technical rights owner was not interested in providing parts so therefore quoted a price at over 30,000 dollars per board. NC3R reverse-engineered these circuit boards, prototype and test first samples, and provided detailed design details to support the purchase of critical repair parts.

Project Results to date:

- Reverse engineered and delivered a detailed technical data package for 3 circuit board assemblies from LAV-C2 intercom.
- Built and delivered five prototype circuit card assemblies, designed board/operational level testing procedures, and provided test results of circuit boards.
- Provided life extension options, with three sources of supply, through next communication revision that could result in a 3.3 million dollar savings for PM-LAV with a planned 100 board buy.

Completed Projects

1. Remanufacturing of Light Armor Vehicle:

Remanufacturing of Light Armor Vehicle Drive Shafts, Completed July 2004

Project Goal

Develop and demonstrate a restoration technique to recover LAV drive shafts that are scrapped.

Approximately 90 percent of LAV drive shafts are currently being scrapped at the USMC Maintenance Depot in Albany, GA because of coating disbonding and rusting beneath the coating. Remanufacturing or restoring these drive shafts will save the Maintenance Depot approximately $3.6 million per year. In addition, the readiness of the LAV will be improved because new LAV drive shafts are difficult to obtain. For this reason, several LAVs are sidelined waiting for new drive shafts.

Instructing restoration process

Project Results

- Developed and demonstrated a process for restoring the drive shafts to a "like new" condition.
- Demonstrated by simulated laboratory testing that new coating has improved wear and corrosion resistance compared to currently used coating.
- Delivered a complete documentation package, including fixture drawing, specifications, and process requirements.

Apple Rubber Drive Shaft Seal Development for Light Armored Vehicle, Completed April 2005

Project Goal

To evaluate a new production replacement double lip drive shaft scraper seal p/n SKC0321 from Apple Rubber Products.

Double lip drive shaft scraper seals were evaluated at NC3R for dimensional tolerances. In addition, an accelerated wear test was designed and fabricated to perform accelerated wear testing on the seals. The dimensions and wear of the Apple seals were compared to OEM double lip drive shaft scraper seals obtained from the Albany Depot.

Project Results

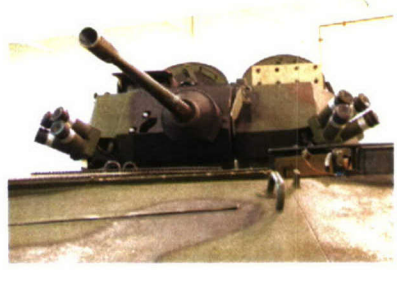
- A report was issued stating that:
  - The measured dimensions and geometry are were within tolerance, and
  - The wear on the new Apple Rubber double lip drive shaft seal scraper was determined to be less than the current seals from Albany in accelerated wear testing at NC3R.

2. Light Armored Vehicle Turret Electronics Trade Study, Completed November 2004

Project Goal

Assess design alternatives for turret drive system, turret electrical distribution, and turret control electronics in order to resolve existing performance problems and component obsolescence issues. Carry forward detailed designs and prototypes for PM-LAV advocated upgrade options.

NC3R worked with PM-LAV to quantify obsolescence issues with current turret components and developed a set of upgrade options that resolve (in order of priority) obsolescence, life-cycle cost, reliability, and performance issues. This assessment is now being used to prioritize investments in component/system redesign and upgrade for the second generation vehicle, LAV-A2.



LAV turret

Project Results

- Analyzed supportability of current turret electronic components and evaluated upgrade opportunities.
- Analyzed LAV electrical power system problems and evaluated technical solutions for performance deficiencies.
- Detailed new technology insertion path for current legacy vehicle and implementation on the next generation vehicle.

3. Light Armored Vehicle Wheel Cover Thermal Signature Analysis, Completed December 2004

Project Goal

Conduct a thermal signature analysis of the new Light Armored Vehicle's aluminum rims for their tires.

NC3R conducted an in-field test, at Camp Pendleton California, of the luminum rims for for the LAV. U.S. Marines vehicle operators conducted a tactical roadmarch over rolling

terrain while engineers from NC3R took thermal measurements at various rim surface locations using non-contact thermometers and inside the wheel planetaries using NC3R designed thermocouple sensors.

Project Results

- NC3R installed and tested wired thermocouple sensors on two Light Armored Vehicles.
- NC3R testing verified that new aluminum rims would not have a greater impact on the overall thermal signature of the Light Armored Vehicle.

4. Light Armored Vehicle Command and Control (C2) Variant Power Study, Completed February 2005

Project Goal

Determine the impact of the Service Life Extension Program (SLEP) on the overall power performance of the Light Armored Vehicle Command and Control (C2) variant and consider the impact of future technology insertions on this performance.

NC3R worked with PM-LAV to conduct a power performance analysis and to analyze the transient load conditions that exist in the SLEP modified LAV-C2 vehicle. Furthermore, NC3R investigated the ability of the LAV-C2 to accommodate future increases in electrical loads with the introduction of new technology.

Project Results

- Provided summary of LAV-C2 power distribution and document its performance.
- Provided detailed analysis of opportunities in the vehicle's power budget for new technology insertion.

5. Light Armored Vehicle Service Life Extension Program (SLEP) Power Study, Completed February 2005

Project Goal

Determine the impact of the Service Life Extension Program (SLEP) on the overall power performance of the Light Armored Vehicle and investigate perceived power related problems with the post SLEP vehicles.

NC3R worked with the PM-LAV to extend the LAV-25 power data previously collected by contractors and to characterize and analyze the transient load conditions that exist in the SLEP modified LAV-25 vehicle. NC3R also investigated power system related problems to include: Thermal Sighting System and Radio drop out when the turret drive is engaged and the short length of time vehicles can be operational in silent watch. Furthermore NC3R investigated the ability of the LAV-25 to accommodate future increases in turret electrical loads with the introduction of new technology.

Project Results

- Provided summary of LAV Turret Power distribution and documents verified problems with the system design.
- Thorough Analysis of the LAV battery pack and performance.
- Detailed recommendations for potential electrical system improvements.

6. Light Armored Vehicle Turret Deflection Analysis April 2005

Project Goal

Determine the amount of deflection resulting from the application of defined loads at locations of the thermal sight and M36 sight mountings on the LAV-25 Turret and to recommend stiffening options to reduce the deflection values.

NC3R worked with PMLAV to asssit them in solving a targeting problem for the LAV-25 main gun. PMLAV had purchased a new siting system for the vehicle in an effort to improve the accuracy of their weapon system, however resulting tests did prove out the requisite precision improvement. RIT investigated the possibility that the advanced age of the vehicle turret which is well passed it's intended life-cycle may have resulted in the deflection of vehicle turret causing targeting problems. NC3R built a number of physical/computer models and conducted thermal and applied loading in order to fully investigate the failure mechanisms and propose pontential solutions.

Project Results

- Developed a finite element meshed model of the LAV-25 turret.
- Conducted a series of thermal loading and applied loading experiments to consider the impact of thermal expansion and sight loading on the turret deflection.
- Determined that thermal expansion was not a significant factor in the sight misalignment problems and that aging and mechanicl loading were the primary factors.
- Designed a gusset that provided significant improvement in the deflection of the turret and could be the potential solution to the weapon's accuracy problems.

7. Light Armored Vehicle: Turret Auxiliary Power System, Completed November 2005

Project Goal

NC3R worked with PM-LAV to design, build, and test a Turret Auxiliary Power System (TAPS) prototype, providing a second source of power for the key electronic components for the LAV.

Turret auxiliary power system

NC3R worked with the PM-LAV to design a system that would prevent excessive voltage droop that the LAV ground combat vehicle experienced during incidents of short duration, high current

loads that turn off many critical components within the turret. In addition to preserving operational capability, as designed, the TAPS prototype provided for longer periods of "silent watch" a key to the vehicle's reconnaissance mission.

Project Results

- Technical Data Package and Bill of Materials for a TAPS prototype.
- Built two TAPS prototypes one for testing and one for delivery to PMLAV.
- Designed and successfully completed a series of stationary and moving on-board vehicle tests of the RIT TAPS prototype.

8. USSV Functional Analysis and Innovation Based Design, Completed December 2005

Project Goals

The development of a formal design process tool applicable to new product development and life-cycle planning that will increase useful product life and minimize environmental impact through cost-effective, incremental technology integration.

NC3R developed a life cycle design process that shows the cost implications for an unmanned sea surface vehicle.

Project Results

- Development of a structured design process tool for new product design.
- Identification of "Decision-making tools" that utilize technology forecasting, operations impact metrics, and technology performance metrics to facilitate quantitative comparison of design options.
- Evaluation of competing technologies to evaluate risk of each design.

Innovation-Based Design

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